UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Office of Earthquake Studies

SUMMARIES OF TECHNICAL REPORTS, VOLUME IX

Prepared by Participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

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

Menlo Park, California

1980

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

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

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UNITED STATES
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Prepared by Participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

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Open File Report No. 80-6

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Earthquake Hazards Reduction Program

Tectonic Framework San Francisco Bay Region

9540-01618

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Investigations

1. Completion of several geologic and liquefaction potential maps for northern Monterey and southern Santa Cruz Counties. Work done by W. R. Dupré.

2. Completion of revised geologic map for San Mateo County. Cooperative work with E. H. Pampeyan.

3. Completion of geologic map of La Honda and San Gregorio quadrangles.

4. Coordination of studies for seismic zonation in the San Francisco Bay region.

5. Coordination of field trips for Japanese landslide experts.

6. Prepared evaluation of geologic data relevant to the General Electric Test Reactor at Vallecitos, California. Cooperative work with D. G. Herd, J. F. Devine, and R. H. Morris.

Results

1. W. R. Dupré has completed mapping surficial deposits and liquefaction potential of the Watsonville East, Watsonville West, Marina, Moss Landing, Natividad, Prunedale, Salinas, and San Juan Bautista 7.5' quadrangles. The maps are in Branch review for eventual publication in the Miscellaneous Field Studies series. The mapping project has already generated considerable interest on the part of the Coastal Commission and a NOAA-funded project to evaluate environmental factors in the Elkhorn Slough area. This area was greatly affected by liquefaction during the 1906 earthquake.

2. The geologic map of San Mateo County is the foundation for a series of derivative maps of ground response, liquefaction potential and landslide susceptibility. The map has been revised and redrafted to incorporate the surficial deposits mapping of K. R. Lajoie, E. J. Helley, D. R. Nichols, and D. B. Burke, and the fault zone mapping of R. D. Brown, Jr. This information will be digitized and entered into the BASIS computer system of the Association of Bay Area Governments for eventual production of the various earthquake hazard reduction maps.

3. The geologic map of the La Honda quadrangle was requested by the Branch of Engineering Geology to provide basic data for a map showing earthquake induced landslide areas. The landslide map is intermediate in scale and concept between the detailed map of a small area reproduced in Circular 807 and the small scale landslide susceptibility map underway for all of San Mateo County.

4. Coordination activities centered around the digitization of maps of San Mateo County by the Association of Bay Area Governments. The first map to be digitized is the geologic map. Discussions with Roger Borcherdt, Jim Gibbs, Tom Fumal, Les Youd, Gerry Wiecjorek and Jeannie Perkins (ABAG) indicate that the geologic units can be combined and grouped in certain ways to produce the first generation ground response and liquefaction maps. The second map to be produced in digital form will be a map showing slope. The slope map in combination with the geologic map, landslide inventory, vegetation map, and possibly other maps will be used to make a rainfall-induced landslide map.

5. Seventeen landslide experts from governmental agencies, universities, and private companies in Japan participated in a tour of major landslide areas along the Pacific Coast arranged in part by the U.S. Geological Survey. They visited several landslide areas near Los Angeles, including areas that failed during the 1971 San Fernando earthquake, and continued with visits to landslides near San Francisco, the Columbia River, and British Columbia. A hand-assembled guidebook of the trip is available for reference in the Menlo Park library of the Geological Survey.

6. Dislocations in the vicinity of the General Electric Test Reactor at Vallecitos, California, have been interpreted by consultants to General Electric as slip surfaces related to landsliding, whereas geologists for the Geological Survey believe they are thrust faults. The zone of thrust faulting is at least 600 m wide; the faults cut the youngest soil of Holocene age; the reactor is located within the zone of faulting. The length, total width, geometry, and age of all of the faulting have not been satisfactorily determined, so it is not yet possible to arrive at reasonable estimates of the earthquake size and resulting ground motion that could affect the reactor.

<u>Reports</u>

Brabb, E. E., Herd, D. G., and Devine, J. F., 1979, Geologic and seismologic data relevant to the General Electric Test Reactor at Vallecitos, California: U.S. Geological Survey administrative report, 18 p.

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

9940-02090

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Investigations

Quaternary geology of northern Los Angeles County and vicinity; stratigraphy, physical properties, and structure of surficial deposits in the Antelope Valley, the adjacent valleys of the San Andreas rift zone, and canyons of the northern San Gabriel and southern Tehachapi Mountains.

Results

The stratigraphic record of late Quaternary deposition during deformation in the study area is about worked out. There have been six episodes of alluviation in the valleys and canyons of the region in the past half-million years that are apparently coincident with the most recent major glacio-pluvial climatic intervals. The distribution and deformation of these deposits records uplift of the San Gabriel and Tehachapi Mountains, north-south shortening of the crust between the San Andreas and Garlock faults, and apparently, increasing flexure in the Big Bend of the San Andreas fault.

The north flank of the central San Gabriel Mountains is folded and thrust northward over asymmetric structural basins beneath the Antelope Valley. Thrust faulting and tight folding near right-lateral faults of the San Andreas system transforms northward within the valley into conjugate groups of many small right- and left-lateral faults on the north valley margin. These groups resolve to the east into the large northwest-trending right-lateral faults of the central Mojave system. The Tehachapi Mountains bordering northwestern Antelope Valley are uplifted as a southward-tilted block that is divided into rhomboid pieces by conjugate strike-slip faults and south-dipping thrust faults.

Activity on structures within the region appears to be episodic; bracketing of times of activity on faults and folds in the stratigraphic framework of distinct deposits of separate alluvial intervals indicates pulses of activity occurred along structures bordering the San Andreas and Garlock faults at different times during the late Quaternary. Vertical rates of local Holocene warping of closed basin pluvial shorelines in northeastern Antelope Valley are as much as one millimeter per year. Warping of late Quaternary alluvium on the north flank of the San Gabriel Mountains indicates variable uplift of the range above the Antelope Valley basins by as much as three millimeters per year. The geometry of faults and folds in the wedge between the San Andreas and Garlock faults and anomalous paleomagnetic poles for Cenozoic rocks on fault blocks in the central Mojave right-lateral system suggest north-south closure of the wedge at a net rate of about .01 microstrain per year for the past half-million and ten million year intervals.

An MF map showing the Quaternary geology of the eastern third of the area at 1:62,500 scale is in review. Maps of the other two-thirds and large scale maps of specific structures remain in progress, as do studies of subsurface Antelope Valley stratigraphy from well logs and physical properties of near-surface materials from soils and engineering studies.

Lines and quadrilaterals of surveying monuments have been installed to record future displacements on the more recently active larger structures in the region.

Reports

Ponti, D. J., and Burke, D. B., 1979, Stratigraphy and deformation of Quaternary sediments in the Antelope Valley, northern Los Angeles County, California: Geol. Soc. America, Abs. with programs, v. 11, no. 7, p. 497.

Vertical Tectonics

9950-01484

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Investigations

1. Continued studies of historic crustal deformation based on repeated spirit levelings and both continuous and discontinuous sea-level measurements, and its relations to the late Cenozoic tectonics in selected parts of California. Although nearly all of our efforts continue to be concentrated in southern California, an increasing effort is being devoted to an assessment of the vertical control record north of the 37th parallel.

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

3. Completed investigation of the so-called sea-slope problem. This problem is manifested both as: (1) discrepancies in the stationary sea-surface topography based on geodetic leveling versus that based on steric leveling; and (2) as geodetically determined changes in the sea-surface topography that remain undisclosed in the local sea-level records obtained at primary tide stations.

Results

1. Acquisition of new leveling data developed by the Bureau of Engineering of the City of Los Angeles demonstrates that probably episodic tectonic movement has continued in the metropolitan Los Angeles area since the completion of the 1978 general releveling. These data, plus discrepancies between the results of the 1978 leveling and the probable configuration of the stationary sea-surface topography, indicate that the 1978 above limits network misclosures are almost certainly attributable to intrasurvey movement. Hence it is now clear that the 1978 releveling, even though it was completed within a five-month period, failed to provide us with an unambiguous "instant" datum, one of the most important targets of this program. Despite continuing uncertainty regarding the validity of the height differences generated during the 1978 comprehensive releveling, the leveling results demonstrate fairly unequivocally that between 1974 and 1978 (and probably largely within the period 1974-76) the southern California uplift sustained pervasive collapse characterized by a generally down-to-the-north tilting.

2. Preliminary results of our investigation of the sea-slope problem indicate that, whatever its origins, it is non-global in its distribution and confined to two fairly well defined physical regimes. Secondly, it

is very unlikely that the resolution of this problem will be found in a simple, single-explanation solution. Thus, while certain specific questions remain unresolved (and perhaps unresolvable), it now seems likely that this seeming problem owes its existence to: (1) distorted height differences produced in response to intrasurvey movement during the time-consumptive leveling process; and (2) a breakdown in steric leveling in areas of strong boundary currents.

Quaternary Faulting in Southern California

9940-01293

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Investigations

1. Investigate epicentral region of the M 5.7 earthquake on August 6, 1979 near Coyote Lake, central California.

2. Examine cores taken from opposite sides of the Garlock fault on Koehn Dry Lake.

3. Analyze Lone Pine scarp in southern Owens Valley (M.S. Thesis at Stanford by Lester Lubetkin, supported partially by this project).

Results

1. Andrei Sarna-Wojcicki and I reached the epicentral region of the August 6 earthquake 3 hours after the main shock. Although we found no surface ruptures along mapped traces of the Calaveras fault next to Coyote Lake (the part of the fault nearest to the epicenter) we did find en-echelon fractures with up to 2 mm of right-lateral offset locally in roads and fields along the fault several kilometers further to the southeast. Two more road crossings of the Calaveras fault further to the southeast than these showed new fractures with as much as 5 mm of right-lateral offset. Overall, the discontinuous zone of fractures that we found along the fault (evident mostly in roads) was 14.5 km long, entirely southeast of the epicenter.

2. Two 2½" diameter cores were taken from opposite sides of the Garlock fault in Koehn Dry Lake by Chuck Hedel and Bill Halbert in December 1978. Core recovery was modest, and some of what was recovered was disturbed by drilling. Maximum depth was 41 m.

Preliminary radiographic and visual examination of the cores by people in John Sims' sedimentary structures lab shows several ash layers in each core. We will now attempt to identify and correlate these ashes with dated sources. Our main objective is to establish a vertical slip rate for the fault at the drilling location.

3. Lester Lubetkin's study of the morphology and stratigraphy of the Lone Pine scarp indicates 1-2 m of dip slip and 6-7 m of strike slip in 1872 along the prominent compound scarp just west of the town of Lone Pine.

Consideration of the 1872 offset, scarp profiles, and bands of desert varnish on large boulders exposed in the face of the scarp indicate that three 1872-type events would be required to produce the present 6-m high scarp. The scarp has developed in an outwash fan of latest Pleistocene age (10-22,000 y.

old), hence, an average recurrence interval for 1872-type earthquakes at this location is in the range of 3,000-7,000 years.

Reports

Herd, D. G., McLaughlin, R. J., Sarna-Wojcicki, A. M., Clark, M. M., Lee, W. H. K., Sharp, R. V., Sorg, D. H., Stuart, W. D., Harsh, P. W., and Mark, R. K., Surface faulting accompanying, The August 6, 1979 Coyote Lake earthquake (Abs.): AGU Fall meeting, 1979, in press.

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

14-08-0001-17676

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Investigations

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

Results

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

2. The Holocene shear pattern is dominated by left-stepping right shears which often bound linear pressure ridges of similar orientation.

3. Where deep canyons cut the fault zone in the western part of the area, it is found that Tertiary and older crystalline rocks have been squeezed up along the fault zone and thrust over both late Quaternary surfaces and deposits.

4. Although our studies show considerable evidence of continuing late Quaternary right-slip, no compelling evidence of significant regional vertical slip was found.

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

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

7. Three map sheets have been completed but not yet published which are believed to be the most detailed so far prepared of landforms and fault features in the Big Bend area of the San Andreas fault.

8. A discontinuously exposed north-dipping thrust fault, the Caballo Canyon fault, has been mapped for a distance of about 16 km, 1 km north of and generally parallel to the San Andreas fault. This thrust appears to have been active from late Oligocene to early Miocene, brings Paleozoic metasedimentary and Mesozoic granitic rocks over probable Miocene Temblor Formation, and may represent an earlier precursor of the modern San Andreas fault.

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

Reports

Crippen, R. E., 1979, Landforms of the Frazier Mountain region, southern California, unpublished M.A. thesis, University of California, Santa Barbara, 304 p.

Davis, T., 1979, Caballo Canyon Fault, San Emigdio Mtns., California, Abstract, Geol. Soc. Am. National Meetings, San Diego, November 1979.

Davis, T., Campbell, S., and Reseigh, D., 1979, Late Quaternary vertical deformation along the north flank of the San Emigdio Mountains, California, Abstract, Geol. Soc. Am.

Davis, T., and Duebendorfer, E., 1979, Strip map of the western Big Bend segment of the San Andreas fault zone, California. Poster Session, Geol. Soc. Am. Cordilleran Section Meeting, San Jose, 11 April 1979.

Duebendorfer, E., 1979, Geology of the Frazier Park-Cuddy Valley area, California, unpublished M.A. thesis, University of California, Santa Barbara, 123 p.

Quaternary Tectonics, Offshore Los Angeles San Diego Area

9460-01650

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Investigations

This study addresses two separable, but related, problems: (1) determinations of the total length of the Palos Verdes Hills fault zone in offshore southern California and its tectonic relationship to the Newport-Inglewood-Rose Canyon fault system, and (2) determination of the history of displacement along the Palos Verdes Hills fault zone, with emphasis on Quaternary offset.

Results

1. A detailed (4 to 8 km line spacing) marine geophysical survey and selective sea floor sampling in the Gulf of Catalina between Los Angeles and San Diego was completed 23 April 1979. These data consist of deep-penetration 160 kj single-channel Sparker, high-resolution Uniboom and 3.5 kHz continuous seismic reflection profiles, and 12 kHz bathymetric, magnetic and gravity profiles. Side-scan sonography was done in selected areas of the shelf offshore of the San Onofre Nuclear Power Plant and on the outer San Pedro shelf. Dart and gravity cores were collected from selected areas adjacent to faults that exhibit sea floor offset; this was done principally to determine the most recent movement along the faults.

2. Interpretation of the data indicates a predominant northwest-southeast structural trench (Figure 1). Two major fault zones within the Gulf of Santa Catalina bound a relatively underformed structural block called the Catalina block. The Newport-Inglewood-Rose Canyon fault zone forms the northeast boundary of this block and the Palos Verdes Hills-Coronado Bank fault zone forms the southwest boundary. Both of these fault zones are composed of discontinuous, generally right-stepping, en-echelon faults and associated folds. No single fault within either zone appears to continue uninterrupted for more than 40 km. This pattern resembles other fault zones of California, onshore and offshore, which are composed of short, en-echelon faults in relatively narrow (1 to 10 km wide) zones.

3. The Newport-Inglewood-Rose Canyon fault zone, which extends offshore at Newport Beach, appears to have influenced development of the eastern slope of the Gulf of Santa Catalina physiographic basin. The zone is defined at the surface by discontinuous, generally northwest-trending faults and folds within Tertiary and Quaternary strata; these structural features form a discrete belt that extends for at least 240 km near the Santa Monica Mountains into Baja California. To the south, near Oceanside, the faults of this zone step to the west and continue southward to La Jolla. Onshore and northwest of Newport Beach, the fault zone extends northward across the western Los Angeles Basin and appears to terminate abruptly at the Santa Monica fault.

4. Scripps submarine canyon appears to be a right-laterally offset head of La Jolla submarine canyon. The inner, north-trending segment of La Jolla Canyon also is fault-controlled; it probably was formed by erosion along a shear zone created by motion along the Rose Canyon faults.

5. The Palos Verdes Hills-Coronado Bank fault zone extends from Santa Monica to Loma Sea Valley and beyond. The segment of the fault zone near San Pedro forms the western margin of the Catalina block and is well-defined and continuous. However, farther south it is discontinuous along the eastern edge of Lasuen Knoll. Here strands of the fault zone step westward, directly along the western edge of Lasuen Knoll. This fault zone may be traced southward for 30 km or more, to its intersection with a more north-trending fault. From this intersection, the Palos Verdes Hills-Coronado Bank fault zone continues southward as two separate segments skirting the eastern edge of Coronado Bank. Quaternary development of Loma Sea Valley and the eastern slope of the Coronado Bank appear to have been structurally controlled by this fault.

6. Major structural and physiographic features within and bounding the Catalina block are compatible with the model of wrench tectonics. It appears that La Jolla submarine canyon, for example, is a graben that has formed as the result of tension associated with dilation within the Catalina block. Coronado Bank, Point Loma, and other banks and ridges within and adjacent to the Catalina block appear to be horsts produced by compressions.

Reports

Greene, H. G., Bailey, K. A., Clarke, S. H., Ziony, J. I., and Kennedy, M. P., (in press), Implications of fault patterns of the inner California Continental Borderland between San Pedro and San Diego; Field Guide, GSA 1979 Annual Meeting, San Diego, California.

Geophysical Studies, Western Transverse Ranges

9730-00363A

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Investigations

1. Geophysical studies of the western Transverse Ranges, California, in the Los Angeles 1°x2° sheet by obtaining information on the location, distribution, and configuration of concealed and exposed magnetic rock units from aeromagnetic data interpreted in conjunction with available gravity, seismic, and geologic data.

2. The studies will focus on the tectonics of the study region with particular emphasis on relationships to active or recently active faults, to areas of active uplift or subsidence, and to areas of active seismicity.

Results

Results of this project have been reported upon in previous volumes of the Summaries of Technical Reports. A final report on this investigation is in preparation and should be completed before the next report period.

San Francisco Region Geophysics

9730-00363B

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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

Results of this project have been reported upon in previous volumes of the Summaries of Technical Reports. A final report on this investigation is in preparation and should be completed before the next report period.

Neotectonics of the San Francisco Bay Region, California

9540-01950

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Investigations

1. With Brett Cox of Project No. 9540-01616, Earthquake Hazards Studies, Upper Santa Ana Valley and Adjacent Areas, Southern California (D. Morton, Chief), a reconnaissance study of the glacial geology of the San Bernardino Mountains was continued. Reconstructed snowlines (equilibrium-line altitudes) of former glaciers were used to assess whether the San Bernardino Mountains east of Los Angeles, California, have been uplifted in the late Quaternary. The mountains, which rise near the center of the southern California uplift (Palmdale Bulge), were elevated temporarily between 1959 and 1974 at a rate of nearly 10 mm/yr.

2. A cooperative search with other members of the U.S. Geological Survey staff was made for surface faulting along the Calaveras fault zone following the Coyote Lake earthquake of August 6, 1979. The magnitude 5.7±0.2 earthquake occurred on the fault zone east of Gilroy, California.

3. The seismic hazard for the San Francisco Bay region was calculated from geologic and seismologic data with R. K. McGuire and K. M. Shedlock of Project No. 9950-01733, Methodologies for Seismic Risk Assessment (R. K. McGuire, Chief). Risk levels were assigned by determining the acceleration that would likely accompany earthquakes on recently active faults in the San Francisco Bay area.

4. Large-scale (1:24,000) mapping of late Quaternary faulting in the central Calaveras fault zone (between Hollister and Calaveras Reservoir, California), the southern Hayward fault zone, and Evergreen fault zone was completed. The recency, location, and character of faulting was investigated by aerial photographic interpretation and reconnaissance field mapping.

5. A final review of the earthquake hazards and geology of the General Electric Test Reactor at Vallecitos Nuclear Center, Pleasanton, California, was completed for the Nuclear Regulatory Commission. The reactor was closed in October 1977 by the Nuclear Regulatory Commission following the release of U.S. Geological Survey Open-File Report 77-689 (Herd, 1977). In that report, the active Verona fault was mapped to pass within 60 m of the reactor vessel.

Results

1. The snowline of the last glacial maximum (18,000 B.P.?) in the San Bernardino Mountains was determined to lie only 160 m below that of a readvance which based on soil development and weathering criteria appears to be the last Pleistocene ice advance (10,000-12,000 B.P.). The snowlines of

the two ice advances are abnormally close elevationally. Several studies of equilibrium-line altitudes of former alpine glaciers in different hemispheres suggest that the snowlines of the two late Pleistocene glaciations should be separated by 300-450 m. In these latitudes the snowline was generally depressed about 500-550 m below present levels between 10,000-12,000 B.P., and about 850-950 m during the last glacial maximum 18,000 years ago. The 140-290 m snowline compression could reflect an anomalously severe cooling of southern California between 10,000-12,000 years ago (for which there is no climatic evidence). Alternatively, the close proximity of the two snowlines could represent uplift of the range (and a resulting apparent drop in snowline) between 10,000 and 18,000 B.P. The calculated rate of uplift (18-36 mm/yr) would be one of the fastest documented, but would equal the 13-20 mm/yr uplift determined (Sarna and others, 1979; Yerkes and others, in press) in the Western Transverse Ranges north of Los Angeles.

2. Discontinuous surface faulting was observed along a 14.4-km length of the Calaveras fault zone east of Gilroy, California, following the Coyote Lake earthquake. Fresh en echelon fractures in pavement and soil were discovered at several localities along the recently active trace of the fault, locally superimposed on older cracks and breaks. The discontinuous rupture extended northwestward from a point about 5 km southeast of San Felipe Lake (near Hollister, California) to within 6 km of the main shock. No surface faulting was seen in the epicentral area near Coyote Lake. A maximum offset of 5 mm was measured in right-laterally offset curbs along California Highway 152 at the north edge of San Felipe Lake.

3. Ground acceleration that would likely accompany earthquakes on principal recently active faults in the San Francisco Bay region was calculated from geologic data. Earthquake magnitude ranges were determined using historical seismicity and the presence or absence of low level seismicity. Maximum magnitudes were determined using the earthquake magnitude/fault length curves of Slemmons (1977), assuming that the entire fault length could rupture during one earthquake.

4. The central Calaveras fault zone (between Hollister and Calaveras Reservoir, California) consists of a relatively narrow (generally $\leq$0.3 km wide) zone of recently active breaks. However, the fault zone noticeably widens just north of San Felipe Lake (north of Hollister), where the fault zone abruptly turns west from a heading of N.21°W. to N.27°W. In San Felipe Valley, east of Coyote, California, the fault zone again widens dramatically. There the Hayward fault zone splays westward from the Calaveras. The Evergreen fault, a fault heretofore believed to be a small branch of the Hayward fault zone east of San Jose, is evidently a much larger break. A line of west-facing escarpments in late Pleistocene alluvium was traced more than 12 km from Evergreen to near Berryessa, California. The scarps are somewhat flattened, and appear to be associated with thrust faulting, rather than strike-slip movement, in the Evergreen fault zone.

5. The U.S. Geological Survey and the Nuclear Regulatory Commission have concluded that the faulting seen near the General Electric Test Reactor at Vallecitos Nuclear Center is associated with an active Verona fault. The fault consists of a zone of northeastward-dipping thrust faults which appear to join the Las Positas fault zone to the southeast of the reactor.

Reports

Brabb, E. E., Herd, D. G., and Devine, J. F., 1979, Geologic and seismologic data relevant to the General Electric Test Reactor at Vallecitos, California: U.S. Geological Survey Administrative Report, 18 p.

Herd, D. G., McLaughlin, R. J., Sarna-Wojcicki, A. M., Clark, M. M., Lee, W. H. K., Sharp, R. V., Sorg, D. H., Stuart, W. D., Harsh, P. W., and Mark, R. K., 1979, Surface faulting accompanying the August 6, 1979 Coyote Lake earthquake (abst.): EOS, American Geophysical Union Transactions, v. 60, in press.

Lee, W. H. K., Herd, D. G., Cagnetti, V., Bakun, W. H., and Rapport, A., 1979, A preliminary study of the Coyote Lake, California, Earthquake of August 6, 1979 and its major aftershocks (abst.): EOS, American Geophysical Union Transactions, v. 60, in press.

Lee, W. H. K., Herd, D. G., Cagnetti, V., Bakun, W. H., and Rapport, A., 1979, A peliminary study of the Coyote Lake earthquake of Augst 6, 1979 and its major aftershocks: U.S. Geological Survey Open-File Report 79-1621,43 p.

Earthquake Hazards Associated with Faults in the Greater Los Angeles Metropolitan Area, Los Angeles County, California, including Faults in the Santa Monica-Raymond, Verdugo-Eagle Rock, and Benedict Canyon Fault Zones

14-08-0001-G-510

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Investigations

Areas of investigation covered by this report are shown on Figure 1.

1. During this reporting period geologic mapping was conducted along the Verdugo, Eagle Rock, San Rafael and eastern Benedict Canyon fault zones by F. Harold Weber, Jr. He also conducted mapping along the eastern Hollywood fault zone and the York Boulevard segment of the Santa Monica-Raymond fault zone. A comprehensive geologic-paleontologic report covering the Repetto Hills has been obtained from Cities Service Oil Company. This report, in contrast to previous geologic reports, indicates that rocks of the Topanga Formation do not crop out in the northern Repetto Hills south of York Boulevard. Because of the structural implications regarding the location of the York Boulevard segment of the Santa Monica-Raymond fault zone and movement along this segment of the zone, additional geologic mapping and paleontologic studies to augment the Cities Service report will be conducted in selected areas north and south of York Boulevard during Fiscal Year 1979-80.

2. A report on the Santa Monica fault in the Beverly Hills-Hollywood area by CDMG project staff in cooperation with R.C. Slade of Geotechnical Consultants, Inc. has been prepared for publication in a future volume of the Bulletin of the Association of Engineering Geologists. This report discusses the application of precise leveling data, oil well data, ground water data, and seismicity data for locating the Santa Monica fault and providing information concerning its recency of activity.

3. Gravity surveys along the Santa Monica-Raymond and Verdugo-Eagle Rock fault zones have been completed along with a Bouguer gravity map, gravity profiles, and two-dimensional (2D) analysis of integrated geologic and gravity data along three gravity traverses across the Santa Monica-Raymond fault zone. The gravity data along the Verdugo-Eagle Rock fault zone will be released during Fiscal Year 1979-80, after completion of final drafting of the gravity map and profiles.

4. A detailed investigation of the soil profile across the Raymond fault zone exposed in a trench at San Marino High School has been completed by CDMG Soil Mineralogist, Glenn Borchardt.

*Formerly with the California Division of Mines and Geology

5. Continuous cores varying in length from 15 to 23 feet have been obtained along a line crossing Lacy Park in San Marino, the area of a natural depression and former sag pond along the Raymond fault. Data from these cores precluded the location of an ideal trench site suitable for obtaining recurrence data for earthquakes associated with the fault; however, Carbon-14 age dates will be obtained to determine the age of the deepest sag pond deposits and, if possible, to determine sedimentation rates.

6. A Carbon-14 age date which will date one earthquake along the Raymond fault is forthcoming from the U.S. Geological Survey. The earthquake was identified from geologic conditions exposed in a pipeline trench near Sunny Slope Reservoir in Pasadena.

Results

1. Relatively recent movement along faults in the Verdugo fault zone is indicated by vertically offset older alluvial deposits, breaks in slope which appear to be fault scarps in alluvial fan deposits, offset relatively youthful alluvial deposits reportedly exposed in a commercial sand and gravel pit, and a subsurface ground water cascade beneath Verdugo Wash.

2. East of Verdugo Wash, the Eagle Rock fault dips 15° to 30° northward and places basement rocks over conglomerate of the Topanga Formation and possibly over older alluvium. Farther eastward, the fault appears to steepen to nearly vertical, although the fault can be observed on older (pre-development) oblique aerial photographs to dip moderately northward in this general vicinity.

3. The San Rafael fault apparently does not join the Eagle Rock fault, but dies out to the north of this fault in a series of disjointed segments in the basement complex of the San Rafael Hills. Geomorphic features along the trace of the fault between the Arroyo Seco and Lacy Park suggest that it has been active in late Quaternary time.

4. Preliminary mapping along the eastern segment of the Benedict Canyon fault indicates that it extends through the Universal City area along the north side of the eastern Santa Monica Mountains. No evidence of movement along this segment in late Quaternary time has been observed during this study; however, gravity and water well data suggest relatively recent offset of alluvial deposits.

5. The Hollywood fault zone is primarily expressed along the base of the Santa Monica Mountains by scarp-like features that consist of south-facing breaks in a very gently inclined erosion surface developed on coalescing older and younger alluvial fans. East of the Los Angeles River a series of gently south-facing breaks in a nearly flat surface underlain by older alluvium probably represents the most recently active trace of the zone. Farther eastward, the zone may die out into a series of folds and lesser faults within shale terrane of the Puente Formation in the northern Repetto Hills. The most recent activity along the zone was probably transferred northward (en echelon) to the west end of the Raymond fault zone.

6. The near surface trace of the Santa Monica fault in the Beverly Hills-Hollywood area is coincident with a zone of differential subsidence which is probably caused primarily by ground water withdrawal north of the fault

where the fault forms at least a partial ground water barrier in alluvial deposits of Pleistocene age. Focal mechanism solutions derived from microearthquake activity near the east end of the Hollywood area suggest that subsurface faults comprising the Santa Monica-Hollywood fault zone in this vicinity are actively undergoing strain accumulation and release.

7. Gravity data generally define the trend of the Santa Monica-Raymond fault zone and have been useful in constructing geologic cross sections across the fault zone, especially in areas where subsurface data are sparse. The data appear to preclude large lateral offset of the fault zone along any conjectural northwest-trending fault in the vicinity of the Los Angeles River. On the contrary, the data, although not conclusive, are more suggestive of continuity of the zone in the area.

8. Chemical, physical, and mineralogical data confirm radiocarbon dates indicating that soils in the San Marino High School trench are no older than 11,000 years B.P. and have been disturbed by fault movement in the late Holocene. Except for the upper 60 cm, there is little evidence for unbroken soil strata overlying the fault. Similarly, very little soil development has occurred since the soil-filled fissure exposed in the trench was formed. One might speculate that the last earthquake occurred during the last few centuries. Although the soil-filled fissure contains 8,400 year-old carbon, the lack of soil development within this material indicates that the fissure material probably did not fall from the surface, but rather, was smeared laterally between the two blocks during a much more recent event. Along this strand, soil development across the Raymond fault zone appears consistent with at least one event since 8,400 years B.P. There is little evidence, however, within the soil profile for more than one earthquake during its development. Either the recurrence interval is on the order of thousands of years, or else movement has occurred along sub-parallel strands of the fault. Maximum vertical offset during the Holocene appears limited to 30 cm along this strand. Lateral offset along this strand is apparent from soil differences traced to differences in parent material on opposite sides of the fault.

Reports

Hill, R.L., 1979, Potrero Canyon fault and University High School escarpment in Field Guide to selected engineering geologic features, Santa Monica Mountains (J.R. Keaton, Chairman): Assoc. of Engineering Geologists, southern California Sect., Annual Field Trip, May 19, 1979, p. 83-103.

Hill, R.L., Slade, R.C., Sprotte, E.C. and Bennett, J.H., 1978, Fault location and fault activity assessment by analysis of historic leveling data, oil well data and ground water data, Beverly Hills-Hollywood area, California in Geologic guide and engineering geology case histories, Los Angeles metropolitan area, California (D.L. Lamar, Chairman): Assoc. of Engineering Geologists, 1st Annual California Sect. Conf., May 12-14, 1978, p. 167-174.

Real, C.R., Hill, R.L. and Sprotte, E.C., 1978, Seismicity and earthquake focal mechanisms of the northern Los Angeles basin (abstract): Seismological Soc. of America, Annual Meeting, Earthquake Notes, v. 49, no. 1, p. 26.

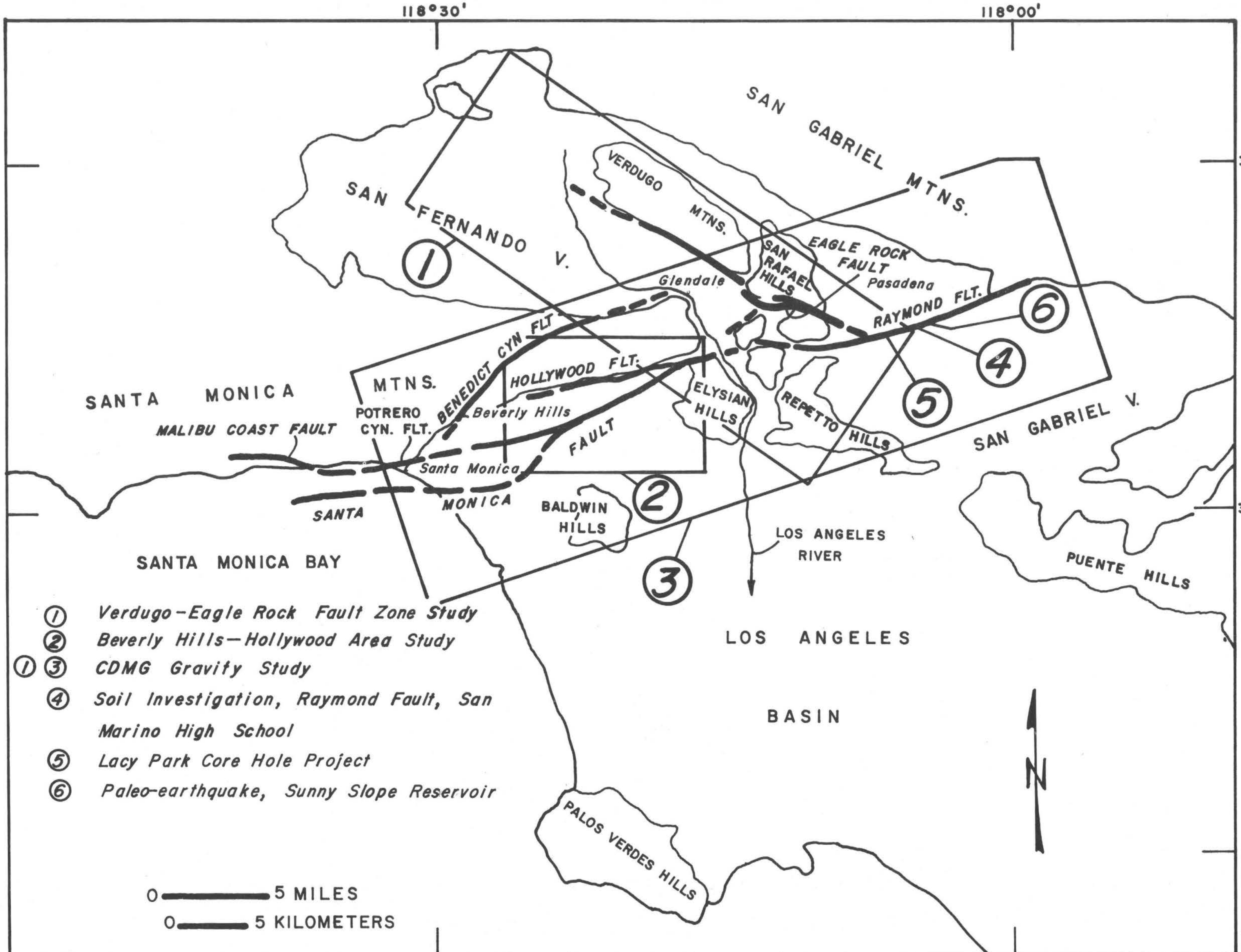

Figure 1, INDEX MAP OF STUDY AREAS

Tectonics of Central and Northern California

9950-01290

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Investigations

1. Study of relations between seismicity and CO_2 discharges continued, in collaboration with Ivan Barnes of Water Resources Division.

2. Measurement of the paleomagnetic orientation of northern California was continued, in collaboration with E. A. Mankinen of Branch of Petrophysics and Remote Sensing.

Results

1. Additional data pertaining to a worldwide relation between CO_2 discharges and seismicity were obtained for China, Afghanistan and Peru and for a few localities along the oceanic ridge systems. The newly acquired data are compatible with the concept that the distribution of CO_2 discharges and the seismicity generally coincide. The presence of CO_2 springs may indicate the presence of high pore pressure at depth and thus a potentially hazardous seismic region. High CO_2 pressure in a fault zone may reduce the effective normal stress and thus facilitate fault slip. Also being investigated is the presence of large concentrations of CO_2 as indicated by commercially productive CO_2 wells in the platform region of North America, and the association of CO_2 springs and other geologic phenomena with intra-plate rift systems.

2. Tectonic analysis has shown that northwestern California consists of a succession of structural plates of oceanic rocks that accreted sequentially during Devonian, Middle Jurassic, Late Jurassic and Early Cretaceous times to form the Klamath Mountains and Coast Ranges (see Irwin and Dennis, 1979). The rocks of some of these plates probably traveled great distances from their points of origin. Terranes of younger rocks in some nearby provinces of Oregon and Washington have been shown by several paleomagnetists to have been rotated clockwise. The rotation is thought by some to result from right lateral movement of a broad NW-SE shear couple that encompasses much of the Pacific Coast region. Similar rotation of the Klamath terranes has not been established, but knowledge of this is important to an understanding of the tectonics of western North America. To investigate this, paleomagnetic samples were cored from the major stratigraphic units that were deposited unconformably on the accreted Klamath terranes. The sampled units are marine Cretaceous strata (Great Valley sequence), continental Eocene beds (Montgomery Creek Fm.) and continental Oligocene beds (Weaverville Fm.). Laboratory work on these samples is now in progress.

Reports

Irwin, W. P., and Dennis, M. D., 1979, Geologic structure section across southern Klamath Mountains, Coast Ranges, and seaward of Point Delgada, California: Geological Society of America Map and Chart Series MC-28D, scale 1:250,000.

Irwin, W. P., 1979, Tectonic accretion of the Klamath Mountains, in The geotectonic development of California, W. G. Ernst, ed.: Rubey Volume No.1, Prentice-Hall, in press.

Irwin, W. P., 1979, Ophiolitic terranes of part of the western United States, in International atlas of ophiolites: Geological Society of America Map and Chart Series MC-33, Sheet 1, scale 1:2,500,000, in press.

Barnes, Ivan, and Irwin, W. P., 1979, Carbon dioxide discharges and seismicity throughout the world (abs): International Geological Congress, 26th Meeting, Paris, in press.

Irwin, W. P., and Barnes, Ivan, 1979, Tectonic relations of carbon-dioxide discharges and earthquakes: Submitted to Journal of Geophysical Research.

Tectonic Geomorphology and Possible Future Seismic Activity of the Central Ventura Basin, California

14-08-0001-17678

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Investigations

1. Evaluation of the newly identified zone of active and potentially active reverse faults near Oak View, California.

2. Earthquake hazard evaluation of active and potentially active faults near Oak View, California.

3. Evaluation of alluvial fan deformation and earthquake hazard along the San Cayetano fault, Central Ventura Basin, California.

Results

1. A zone of active and potentially active reverse faults near Oak View, California is identified (Figure 1) and indicates a need for a reevaluation of the significance of the Ojai Valley to the tectonics of the Western Transverse Ranges. The zone is more than 15 kilometers in length, up to 7 kilometers wide, strikes approximately east-west, and contains at least 11 mappable faults that cut terrace gravels of probably Late Pleistocene age. Individual faults are south-dipping and displacements range from high angle reverse to thrust. The south-side-up relative displacement is in marked contrast with the seismically active San Cayetano and Red Mountain north-dipping faults which bound the zone to the northeast and southwest respectively.

The Red Mountain fault is interpreted to dieout to the east in a set of tight overturned folds east of the Ventura River. Crustal shortening inferred along the San Cayetano fault which apparently terminates to the west near Ojai and the Red Mountain fault may be taken up in part by the newly identified zone of south-dipping south-side-up faults.

Geomorphic expressions of the faulting which suggest Late Pleistocene, if not Holocene, tectonism include: (1) linear escarpments, that separate erosion surfaces veneered with river gravels, and along which faults crop out in several exposures where Miocene sedimentary rocks are faulted over Late Quaternary river gravels; (2) back-tilted surfaces with sag ponds, internal drainage and reversed stream flow; (3) possible deflection of the Ventura River.

2. Several active and potentially active faults in the Ojai Valley near Oak View, California (Figure 1), show bedding-plane or flexural-slip that offset Late Pleistocene river terraces, Holocene colluvium and soil. Faulted

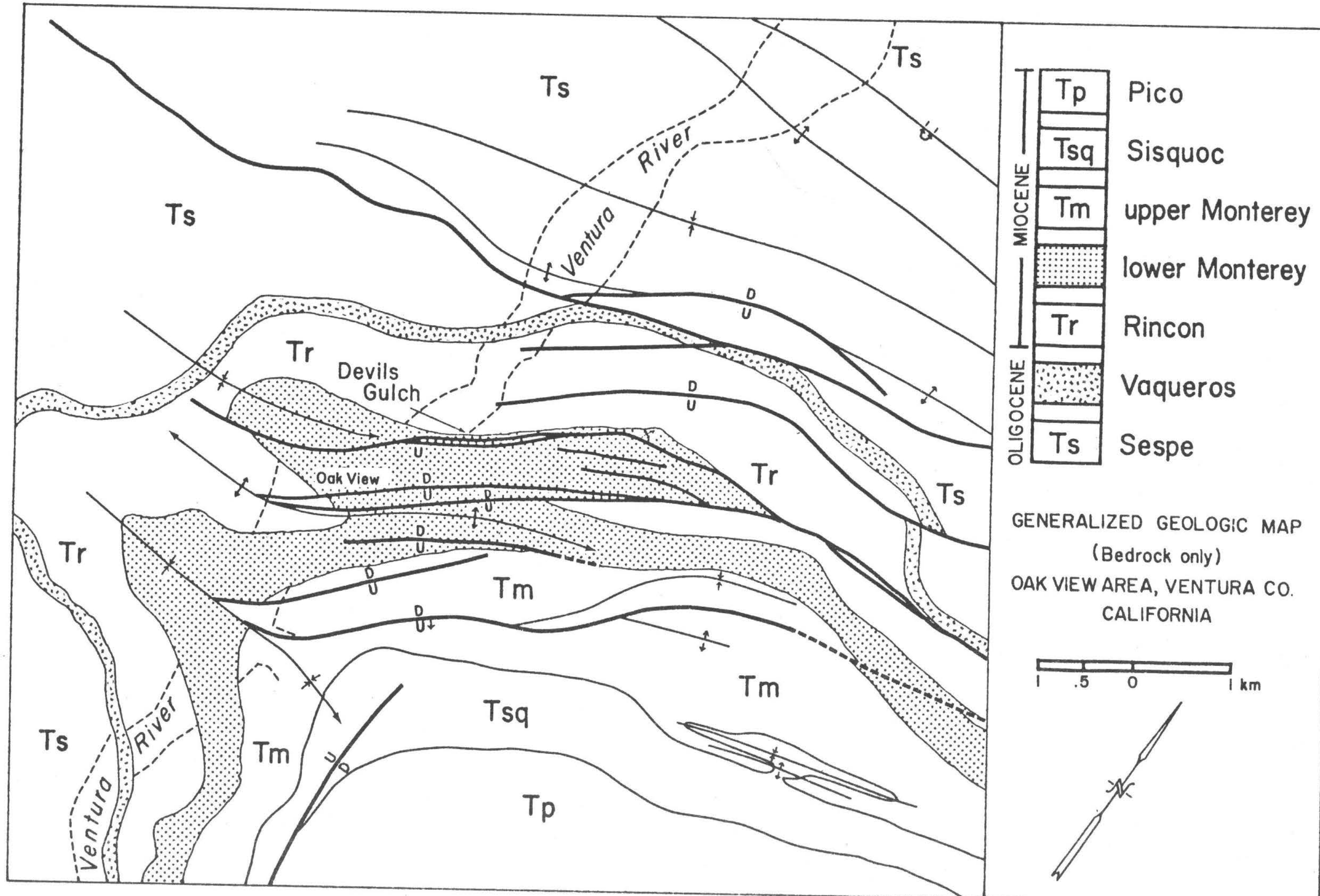

Figure 1. Generalized geologic map (bedrock only) showing synclinorium and zone of active and potentially active south-dipping and south-side-up reverse faulting.

surfaces tilt toward the axis of an underlying synclinorium which suggests that movement along the bedding-plane faults is due to folding of the syncline. Fault planes project along bedding planes into the underlying synclinal trough region rather than cut across the structure. Movement along bedding planes occurs in part on incompetent bentonitic layers and apparently does not extend downward into the basement complex. Thus, it is concluded that movements along these faults are only capable of producing earthquakes of small magnitude. Since the faults are several kilometers long and some of them are active (cut Holocene material), according to published fault length-magnitude earthquake relationships, they may be incorrectly evaluated as capable of producing earthquakes of moderate to large magnitude. They may, however, be associated with local ground rupture during movement, and thus produce a potential surface rupture hazard. Other faults that are similar, from an earthquake hazard perspective, include tensional faults along the crest of an anticline, faults due to surface subsidence and faults related to large landslides.

3. Pleistocene and Holocene alluvial fans on the north side of the Santa Clara River Valley, California, are being actively deformed in conjunction with active thrust faulting along the San Cayetano fault. Several generations of alluvial fans in Orcutt Canyon display tilting, faulting and uplift in proportion to their relative ages as determined from soil profile development. The oldest fan remnants are tilted to 17° with intrafan fault offsets of up to 65 m. Present unfaulted fans have slopes of 6° at the same proximity to the San Cayetano fault indicating at least 11° of basinward tilting. Faulting of the fans occurs both directly by the San Cayetano fault and by bedding plane faults induced by regional north-south convergence. At Sisar Canyon, the main fault trace is represented by a 65-m scarp in Mid- to Late Pleistocene fan deposits. In Orcutt Canyon, the fans begin at the main fault trace where bedrock is faulted up and eroded off, forming long, narrow valley-fill fan deposits. These deposits are faulted by flexural-slip induced bedding plane faults with scarps up to 25 m high in the oldest deposits. Moderate- to large-magnitude earthquakes would only be expected to be generated along the main San Cayetano fault zone which juxtaposes Eocene sandstones and shales over Early to Mid-Pleistocene conglomerates. The bedding plane faults probably only produce small-magnitude earthquakes as they do not extend to depths where larger earthquakes are generated. They do, however, produce a potential ground rupture hazard.

Reports

Clark, Michael and Keller, Edward, 1979, Newly identified zone of potentially active reverse faulting, western Transverse Ranges, California: Geol. Soc. America National Meeting, Abstracts with programs, V. 11, N. 7. pp. 402-403.

PROJECT TITLE: Recency and Character of Faulting Offshore from Metropolitan San Diego, California

CONTRACT NUMBER: 14-08-0001-17699

PRINCIPAL INVESTIGATOR: Michael P. Kennedy

INSTITUTION: California Division of Mines and Geology
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SUMMARY REPORT COVERING PERIOD OCTOBER 1, 1978 TO SEPTEMBER 30, 1979

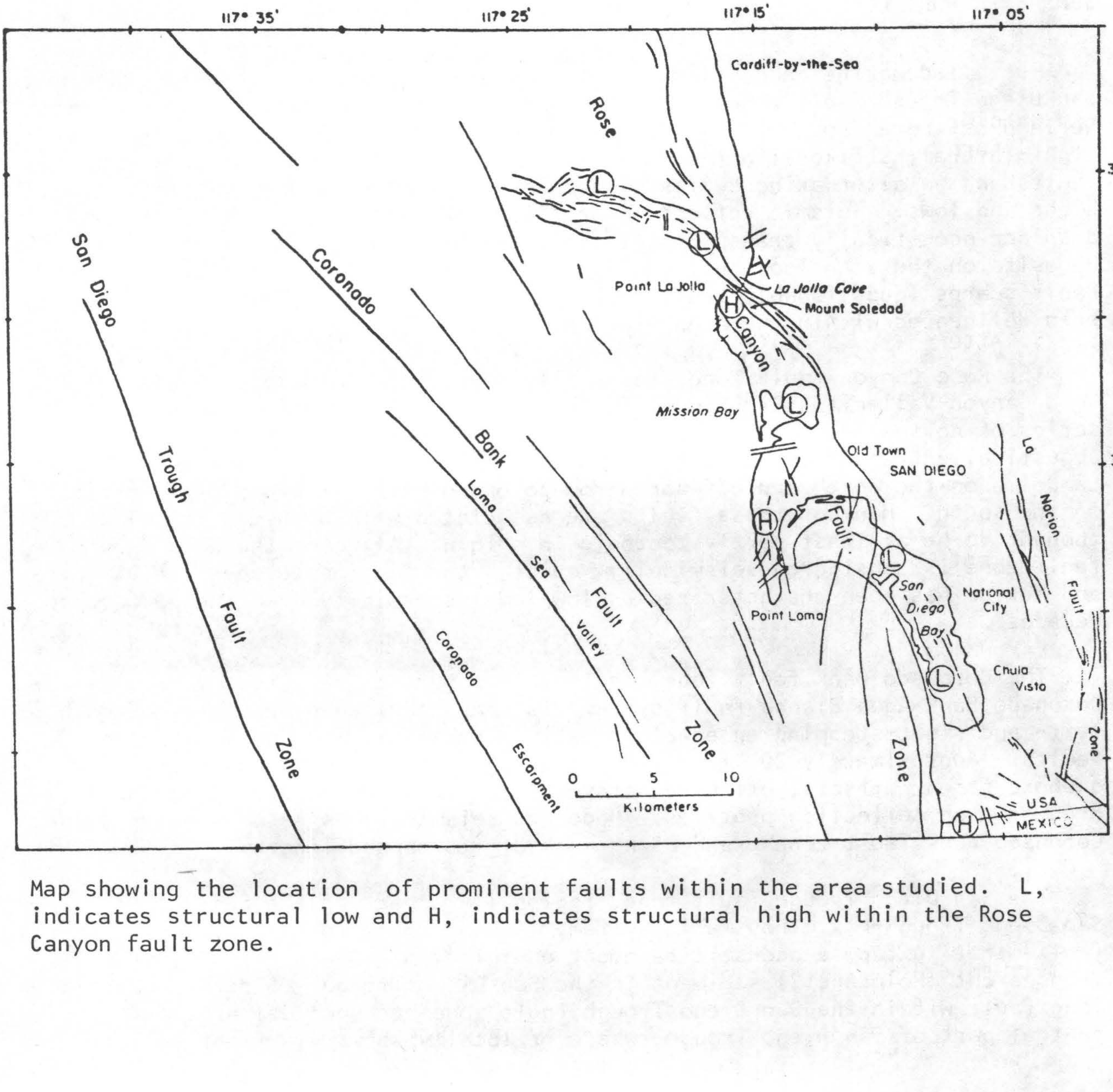
Detailed marine geophysical surveys of the Rose Canyon, Coronado Bank and San Diego Trough fault zones indicate that the inner southern California borderland offshore from metropolitan San Diego is underlain by a Quaternary, right-lateral, strike-slip tectonic regime geologically manifest in youthful faults and an alternating series of compressional and tensional structural highs and lows. Seismic reflection profiles indicate that these fault zones displace acoustically transparent (water saturated and unconsolidated) surficial deposits on the sea floor and locally are associated with bathymetric relief. Fault scarps (questionably fault-line scarps) more than 100 m in height have been delineated within the area studied.

The Rose Canyon fault zone, regionally a part of the Newport-Inglewood-Rose Canyon-Vallecitos-San Miguel fault system is characterized by a complex series of northwest trending Quaternary faults. Faults in this zone displace acoustically transparent (Holocene) sediment on the sea floor offshore from La Jolla on the north and offshore from Coronado near San Diego Civic Center on the south. Many of these faults are associated with bathymetric relief thought to be at least partly tectonic in origin. Although the Rose Canyon fault zone is considered seismically "quiet," the section between San Diego Bay and Mexico has been characterized by low level seismicity over the past three decades.

The Coronado Bank fault zone, regionally a part of the Palos Verdes Hills-Coronado Bank-Agua Blanca fault system, is characterized by a series of both left- and right-stepping en echelon mostly northwest-trending, subparallel faults. Approximately 20 km of right lateral strike-slip is suggested from onshore stream offsets, offshore bathymetric displacements and character of drag seen on reflection profiles. Moderate seismicity is associated with the Coronado Bank fault zone trend along much of its mapped length.

The San Diego Trough fault zone, regionally a part of the San Pedro-San Diego Trough-Maximinos fault system, is characterized by northwest trending faults that juxtapose acoustic basement on Thirty Mile Bank with acoustically transparent (Holocene ?) sediment in the San Diego Trough. A continuous, 22 km long fault within the San Diego Trough fault zone has been delineated in the central part of San Diego Trough, where it locally shows sea floor relief.

Sediment cut by faults in the area has been divided into three informal units based on superposition and acoustic properties. The youngest of these is Holocene and late Pleistocene in age, has a velocity of 1.4-1.7 km/sec and generally is acoustically transparent. The intermediate unit is a lower Quaternary succession that has moderately strong reflection character, generally underlies a veneer of the acoustically transparent sediment and has a velocity of 1.7-1.9 km/sec. The oldest unit is Late Cretaceous and early and middle Tertiary in age, has extremely strong reflection character, and has velocities of 1.9-2.2 km/sec.



Map showing the location of prominent faults within the area studied. L, indicates structural low and H, indicates structural high within the Rose Canyon fault zone.

Coastal Tectonics, Western U.S.

9940-01623

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Investigations:

1. Continuation of mapping and dating late Quaternary marine terraces and deposits from numerous coastal sites in the western U.S. with emphasis on the Humboldt County region, the Point Conception area and the Ventura area of California. Project personnel are George Kennedy and Scott Mathieson. Cooperative field projects are with Andrei Sarna-Wojcicki and Bob Yerkes (OEG) in the Ventura area, with Sam Morrison (Humboldt State U.) in the Humboldt area, and with Gerald Weber in the San Mateo area. Cooperative dating projects are with Etta Peterson (NASA-Ames), John Wehmiller (U. Delaware), Bert Gerow (Stanford) and Steve Robinson (U.S.G.S.).

2. Attended the Cordilleran Section meeting of the GSA and was co-leader with Gerald Weber and Gary Griggs (both U.C. Santa Cruz) of field trip along the Santa Cruz and San Mateo County coasts focusing on marine terrace deformation and active faults.

Results:

1. Five peat and charcoal samples from tectonically deformed sag pond sediments exposed in the sea cliff adjacent to a major strand of the San Gregorio fault at Año Nuevo yield ^{14}C ages of 10,670 ± 220 to 8,460 ± 210 years BP. Six peat horizons in the pond sediments may record separate tectonic events when the pond was deepened due to displacement along the fault.

2. Wood and marine shell samples from marine platforms and beach ridges on the Singley terraces at Cape Mendocino yield ^{14}C dates between 3,130 ± 100 and 3,740 ± 210 years BP. These dates confirm the rapid uplift rates previously obtained. At least three Holocene terrace levels and emergent beach ridges may represent distinct tectonic uplift events over the past 4,000 years in this area.

3. Marine shells from emergent marine terraces (elev. up to 20m) in the Ventura area yield ^{14}C dates of 1,820 ± 40 to 4,155 ± 90 years BP which establish uplift rates >1 mm/year. Historical maps (1870) record at least four minor terraces on the main terrace. These minor terraces may record distinct tectonic uplift events. Emergent marine terraces occur only in Ventura, near Point Conception and Cape Mendocino where tectonic uplift rates

are higher than along any other parts of the California Coast. A terrace remnant at about 40m above sea level may be Holocene in age; If so, uplift rates may be much higher than previously established.

4. A ^{14}C date on nodose tufa from the Wilson Creek beds in Mono Basin places the age of the Mono Basin paleomagnetic excursion at about 29,000 years which is slightly older than previously believed from age estimates based on sedimentation rates.

Reports:

Kennedy, George L., Lajoie, Kenneth R. and Wehmiller, J. F., 1979, Late Pleistocene and Holocene Zoogeography, Pacific Northwest Coast (abs.): Geological Society of America Abstracts with Programs, v. 11, no. 3.

Sarna-Wojcicki, Andrei M., Lajoie, Kenneth R., Robinson, Steven W., and Yerkes Robert F., 1979, Recurrent Holocene Displacement on the Javon Canyon fault, rates of faulting, and regional uplift, western Transverse Ranges, California (abs): Geological Society of America Abstracts with Programs v. 11, no. 3.

Lajoie, Kenneth R., Wehmiller, John F., and Kennedy, George L., (in press), Intergeneric and intrageneric trends in apparent racemization kinetics of amino acids in Quaternary mollusks: Carnegie Institute.

Lajoie, Kenneth R., Peterson, Etta, and Gerow, Bert A., (in press): Amino-acid dating of bone: a feasibility study south San Francisco Bay region, California: Carnegie Institute.

Lajoie, Kenneth R., Kern, J. P., Wehmiller, J. F., Kennedy, G. L., Mathieson, S. A., Sarna-Woicicki, A. M., Yerkes, R. F., McCrory, P. F., 1979, Quaternary terraces and crustal deformation in southern California: in Abbott, P. L., (ed.) Geological Excursions in the southern California area, San Diego State University.

Kennedy, George L., D'Attilio, A., Morrison, S. D., Lajoie, K. R., (in press), Quaternary Bankia (Bivalvia: Terendinidea) from Humboldt County, California: Nautilus.

Muhs, Daniel R., 1979, Marine terrace Age assignments, uplift rates and sea level events on San Clemente Island, California (abs.): Geological Society of America Abstracts with Programs, v. 11, no. 3.

Lajoie, Kenneth R., Kennedy, George L., Sarna-Wojciciki, A. M., Yerkes, R. F., Mathieson, Scott A., and Morrison, Samuel D., 1979, Emergent Holocene marine terraces of coastal California: Tectonic implications (abs.) appendix in Lajoie, K. R., Kern, J. P., Wehmiller, J. F., Kennedy, G. L., Mathieson, S. A., Sarna-Wojcicki, A. M., Yerkes, R. F., McCrory, P. F., 1979, Quaternary terraces and crustal deformation in southern California: in Abbott, P. L., (ed.) Geological Excursions in the southern California area, San Diego State University.

Kennedy, George L., Pleistocene Faunal Provinces of California (abs.): appendix _in_: Lajoie, K. R., Kern, J. P., Wehmiller, J. F., Kennedy, G. L., Mathieson, S. A., Sarna-Wojcicki, A. M., Yerkes, R. F., McCrory, P. F., 1979, Quaternary terraces and crustal deformation in southern California: _in_ Abbott, P. L. (ed.) Geological Excursions in the southern California area, San Diego State University.

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

9540-01616

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Investigations

1. Continued study of the Quaternary Geology in the Upper Santa Ana Valley.

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

3. Continued fault studies in the San Gorgonio Pass-southern San Bernardino Mountains area.

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

5. Trenched the Cucamonga fault on the Day Canyon Fan.

6. With D. Herd (9540-01950) a reconnaissance study of the glacial geology of the San Bernardino Mountains was continued.

Results

1. Three trenches were cut across the most pristine of the fault scarps of the Cucamonga fault zone on Day Canyon Fan north of Fontana, California. All three trenches were in bouldery alluvium. In two of these trenches, fault features were moderately to well defined; in the third only slight expression of faulting was visible. In the trench with the most clearly defined fault features, distribution of material in the toe of the scarp is supportive of multiple episodes of ground rupture. This largely resolves the question can repeated episodes of ground rupture occur in essentially the same position in bouldery alluvium along the Cucamonga fault. The dip of the fault in these trenches was about 40° the same value as most measured dips of the Cucamonga fault traces in bedrock and in basement-alluvium fault contacts; this resolves the question, for the Cucamonga fault, were it cuts essentially unconsolidated bouldery alluvium, if it maintains the low angle dip or steepens. Lack of currently well-defined fault features in the third trench reemphasizes the problem of detecting a fault in crudely bedded bouldery alluvium.

2. The snowline of the last glacial maximum (18,000 B.P.?) in the San Bernardino Mountains was determined to lie only 1650 m below that of a readvance which based on soil development and weathering criteria appears to be the last Pleistocene ice advance (10,000-12,000 B.P.). The snowlines of the two ice advances are abnormally close elevationally. Several studies of equilibrium-line altitudes of former alpine glaciers in different hemispheres

suggest that the snowlines of the two late Pleistocene glaciations should be separated by 300-450 m. In these latitudes the snowline was generally depressed about 500-550 m below present levels between 10,000-12,00 B.P., and about 850-950 m during the last glacial maximum 18,000 years ago. The 140-290 m snowline compression could reflect an anomalously severe cooling of southern California between 10,000-12,000 years ago (for which there is no climatic evidence). Alternatively, the close proximity of the two snowlines could represent uplift of the range (and a resulting apparent drop in snowline) between 10,000 and 18,000 B.P. The calculated rate of uplift (18-36 mm/yr) would be one of the fastest documented, but would equal the 13-20 mm/yr uplift determined (Sarna and others, 1979; Yerkes and others, in press) in the Western Transverse Ranges north of Los Angeles.

Reports

Blake, M. C., Jr., Morton, D. M., Jayko, Angela, 1979, Tectono-stratigraphic terrane map of western Baja California, western California and southwest Oregon: Geological Society of America, Abstract with Programs, p. 389.

Basement Tectonic Framework Studies
San Andreas Fault System

9950-01291

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Investigations

1. Field study of the Breckenridge-Kern Canyon fault zone and the basement rocks on both sides of the zone from the area of Caliente, California, north to the Forks of the Kern; a strike length of about 100 km (60 miles).

2. Field checking of problem areas in the southernmost Sierra Nevada.

3. Write-up of metamorphic rock units for a forthcoming report on the basement framework of the southernmost Sierra Nevada (north to 35°30').

Results

Preliminary evaluation of field data collected along the Breckenridge-Kern Canyon fault zone confirms the right-lateral offsets located further to the north that were noted by Moore and du Bray (Moore, J. G., and du Bray, Edward, 1978, Mapped offset on the right-lateral Kern Canyon fault, southern Sierra Nevada, California: Geology, v. 6, no. 4, p. 205-208.). I have found approximately 13 km of possible right-lateral offset across the fault zone, on several granitic and metamorphic units. The fault itself is a strongly compressional zone of cataclastic deformation, the scope of which may not have been fully appreciated in the past. For example, two areas along the fault zone that had been mapped as metasedimentary rock are, in fact, underlain by strongly deformed granitic rock. The discovery of travertine in both areas may suggest metasedimentary rocks, but I found no marble or other evidence of sedimentary rocks. The travertine might represent old discharges of CO_2 along the fault zone. These strongly deformed granitic rocks in the fault zone are reminiscent of similar rocks that lie along the east side of Owens Valley, at the west base of the Inyo Mountains (Ross, D. C., 1965, Geology of the Independence quadrangle, Inyo County, California: U.S. Geological Survey Bulletin 1181-O, p. O57.).

The Breckenridge-Kern Canyon fault now appears to be seismically quiet--it presumably represents a very old, but fundamental break in the crustal structure of the region. Interestingly enough, it strikes directly into the White Wolf fault zone, a zone of particularly active seismicity. The relation between these two fault zones is presently unknown.

Reports

Ross, D. C., 1979, Basement rock clasts in the Temblor Range, California--some descriptions and problems: U.S. Geological Survey Open-File Report 79-935, 13 p.

Movement and Deformation
on the Southern Foothills Fault System, California
Contract No. 14-08-0001-17724

Report Summary by Richard A. Schweickert
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June 1, 1979

Preliminary laboratory studies of fault rocks collected prior to the beginning of this contract have been completed, and in addition a 4-year structural and stratigraphic study of hanging-wall rocks on the east side of the fault is nearing completion. The latter study suggests that the Late Jurassic Melones fault may have developed along a still earlier, pre-Middle Jurassic ductile fault in the Sierra foothills.

Fieldwork involving detailed structural mapping and strain analysis of fault rocks, and taking oriented cores for paleomagnetic study will be carried out in June, July and August, 1979.

Salton Trough Tectonics

9940-01292

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Investigations

1. Continuation of near-field leveling across the Imperial fault, Imperial Valley, California.

2. Completion of manuscript on variable rates of Late Quaternary strike slip on the San Jacinto fault zone, southern California.

Results

1. The large tilts and fault slip measured between October 1977 and April 1979 across a 210-meter leveling line centered on the Imperial fault at Harris Road apparently have ceased. A releveling on July 6, 1979 showed no significant tilting between ends of the line but a 10-meter wide collapse of 1.2 cm formed just west of the fault trace. The line was extended to 195 meters on each side of the fault because the earlier deformation extended beyond the previous length of the line.

2. Three strike-slip displacements of strata with known approximate ages have been measured at two locations on the San Jacinto fault zone. Minimum horizontal offset between 5.7 and 8.6 km in no more than 0.73 my northeast of Anza indicates $\geq$ 8-12 mm/yr average slip rate since late Pleistocene time. Two measures of more recent displacement are based on trenching studies of stratigraphic offsets on the Coyote Creek fault in western Imperial Valley. Horizontal slip of 1.7 m has been calculated from data of Clark and others (1972) for the youngest sediment of Lake Cahuilla since its deposition 283 to 478 years BP. The corresponding slip rate is between 3 and 5 mm/yr. Right-lateral offset of 10.9 m measured on a buried stream channel older than 5000 but younger than 6800 years BP yields an average slip rate for the intermediate time period (400 $\pm$ to 6000 $\pm$ years BP) of 1-2 mm/yr. The average rates of slip for these three time intervals indicate a major relatively quiescent period for the San Jacinto fault zone from about 4000 BC to about 1600 AD.

To the extent that long-term variations in seismic activity of major strike-slip faults elsewhere are known, the fluctuations in slip rate for the San Jacinto fault zone do not appear to be abnormal. If the San Jacinto and adjacent segments of the San Andreas fault zones alternately assume dominant roles in absorbing motion between the Pacific and American plates, perhaps even more recently than 400 years ago, the San Andreas fault in the northern Salton Trough expressed most of the motion but has since become relatively inactive.

Reports

Sharp, R. V., 1979, New geologic evidence relating the southernmost San Andreas fault to the seismic belt of central Imperial Valley [abs.]: Earthquake Notes, Seismological Society of America, v. 49, no. 4, p. 97.

Sharp, R. V., Akasheh, B., Eshghi, I., and Orsini, N. A., 1979, The Tabas, Iran earthquake of September 16, 1978: Observations on surface faulting [abs.]: Earthquake Notes, Seismological Society of America, v. 49, no. 4, p. 84.

Sharp, R. V., 1979, Recent geologic research on the Imperial fault [abs.]: Program of Symposium on human settlements on the San Andreas fault, Calif. Seismic Safety Comm., Tijuana, B. C., Mexico.

Sharp, R. V., in press, 1940 and prehistoric earthquake displacements on the Imperial fault, Imperial and Mexicali Valleys: Symposium on human settlements on the San Andreas fault, Proc., Dept. of Prevention and Attention on Urban Emergencies, Mexico, D. F.

Sharp, R. V., 1979, Implications on surficial strike-slip fault patterns for simplification and widening with depth, in Proceedings of Conference VIII, Analysis of actual fault zones in bedrock: U. S. Geological Survey Open-File Report 79-1239, p. 66-78.

Sharp, R. V., 1979, Some characteristics of the eastern Peninsular Ranges mylonite zone, in Proceedings of Conference VIII, Analysis of actual fault zones in bedrock: U. S. Geological Survey Open-File Report 70-1239, p. 258-267.

Herd, D. G., McLaughlin, R. J., Sarna-Wojcicki, A. M., Clark, M. M., Lee, W. H. K., Sharp, R. V., Sorg, D. H., Stuart, W. D., Harsh, P. W., and Mark, R. K., 1979, Surface faulting accompanying the August 6, 1979, Coyote Lake earthquake [abs.]: American Geophysical Union, EOS, in press.

Sharp, R. V., 1979, in press, Variable rates of late Quaternary strike slip on the San Jacinto fault zone, southern California: Journal of Geophysical Research.

LATE HOLOCENE BEHAVIOR OF THE SAN ANDREAS FAULT

U.S.G.S. Contract No. 14-08-0001-16774

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This contract supports continuing investigations of the behavior of the faults of the San Andreas fault system during the past several thousand years. The purpose of these studies is to determine the long-term fault slip rates and the frequencies and spatial relationships of large earthquakes along the faults.

Between January and August of 1979 we accomplished the following: (1) Completed excavations at Wallace Creek which confirm a slip rate along the San Andreas fault of $\geqslant$3 to 4 cm/yr and an average recurrence of 10-m slip events of $\leqslant$250 to 330 years there. (2) I continued field studies at Van Matre Ranch in the Carrizo Plain, where the past three events were associated with 8 to 10 m of slip, and a fascinating story of late Pleistocene and Holocene tectonic activity is unfolding. (3) Elizabeth Thomas began a study of the young and severely deformed Elkhorn Hills at the northwestern end of the "Big Bend". (4) Kristian Meisling and I finished a manuscript which describes our study of trees along the fault that were affected by the 1857 earthquake. (5) New evidence from extensive excavations at Pallett Creek indicates a) perhaps 4 earthquakes occurred between 500 A.D. and 500 B.C.(?), b) all nine earthquakes since 500 A.D. were large events, c) a possible event previously unrecognized at about the 1600 A.D. level may reduce the average recurrence interval from about 160 to about 145 years, and d) the range of recurrence intervals may be reduced from about 55-275 years to about 100-230 years. Plan-view maps of each earthquake at Pallett Creek show how each event has been associated with slightly different faulting, folding, and liquefaction phenomena, even though the principal trace has not changed greatly from event to event. Maps of offset facies in 200 to 2000 year old strata may yield slip rates and the amount of slip per event at Pallett Creek. (6) Ray Weldon began a study of the offset Holocene (?) Lone Pine Canyon terraces near Cajon Pass, in an attempt to discover the slip rate along the San Andreas fault at that locality. (7) I completed field work along the dormant southern segment of the San Andreas fault aimed at determining the amount of fault slip associated with the latest (prehistoric) event(s).

Along the freshest part of that segment, smallest offsets range from 2 to 5 meters. (8) And finally, I have found a site at the intersection of the San Andreas fault and the northern shoreline of ancient Lake Cahuilla where the dating of prehistoric earthquakes may be possible.

Seismic Hazard Study of the Western Portion of the Garlock Fault

14-08-0001-17791

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Investigations

Three sites with a high potential for determining the recent history of movement on the Garlock fault were selected based on analysis of aerial photographs and field reconnaissance (Fig. 1). Detailed investigations, including seismic refraction surveys, topographic surveys and geologic mapping provided positive evidence for fault offsets in young dateable deposits at Twin Lakes and Oak Creek Canyon.

Exploratory trenching has been conducted at Twin Lakes and geomorphic analysis of offset topographic features is continuing at Oak Creek Canyon. Samples for radiocarbon and paleomagnetic age-dating have been collected at both sites.

The current work will be combined with previous investigations at Castac Lake (LaViolette and others, 1979) to evaluate the seismic hazards associated with this segment of the Garlock fault zone.

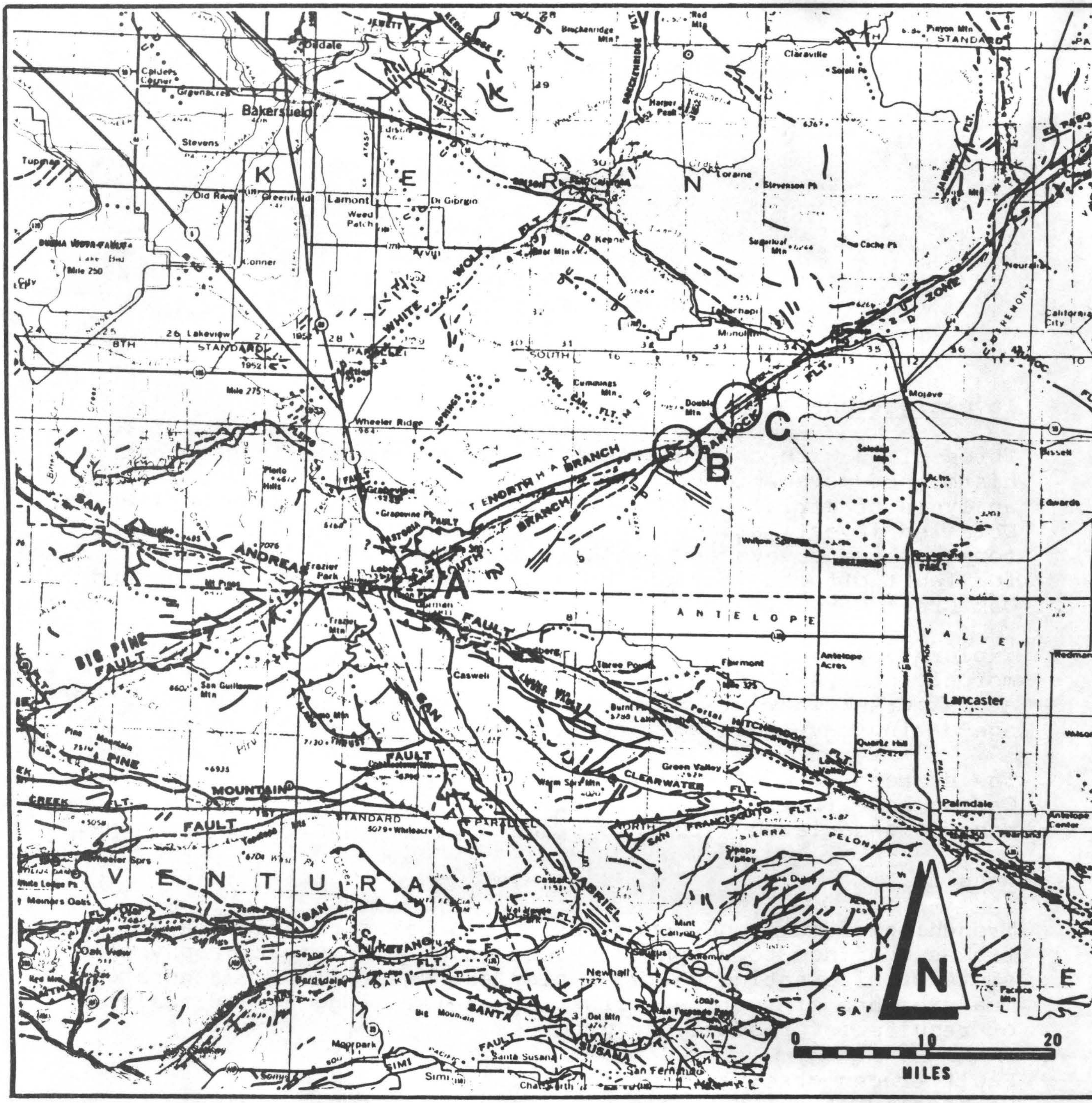
Results

Trenching of sag pond deposits at Twin Lakes revealed fault traces confined to a zone 3 meters wide. The stratigraphy consists of alternating units of clay and sand allowing accurate measurements of vertical offset. Detailed logging and analysis of results is presently in progress.

Fault tràces observed in stream channels at Oak Creek Canyon vertically offset dateable horizons. Geomorphic analysis of offset topographic features is in progress, but results to date are inconclusive in terms of amounts or rates of left-lateral displacement.

Reports

LaViolette, J. W., Guacci, G., Payne, C. M., and Grannell, R. B., 1979, Seismic hazard study of the Garlock fault at Castac Lake, Lebec, California: Geological Society of America, Abstracts with Programs, V. 11, no. 7, p. 463.



NOTE: BASE MAP FROM JENNINGS, 1975 FAULT MAP OF CALIFORNIA

EXPLANATION

A CASTAC LAKE

B TWIN LAKES

C OAK CREEK CANYON

FIGURE 1

LOCATION OF STUDY AREAS
GARLOCK FAULT

Quaternary Framework for Earthquake Studies Los Angeles, California

9540-01611

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Investigations

1. Continued 1/24,000 geomorphic/photogeologic/soil stratigraphic mapping of surficial geology of the Los Angeles basin.

2. Continued preparation of preliminary surficial materials maps of San Gabriel Valley, San Fernando Valley and the coastal plain of Los Angeles County.

3. Completed compilation of a geologic and geotechnical data base in support of seismic zonation studies in the Los Angeles Basin.

4. Submitted for pre-editing a compilation of 850 ^{14}C dates.

5. Completed selection of regionally significant, pedogenic soil profiles to be sampled for quantitative chemical analyses in the Los Angeles basin.

6. Completed compilation of a geotechnical data base in support of liquefaction susceptibility mapping in the San Fernando Valley.

Results

1. 1/24,000 scale mapping is 60 percent completed in the coastal plain of Los Angeles County.

2. 1/125,000 preliminary surficial materials maps of San Gabriel Valley and Coastal Plain of Los Angeles County are drafted and will be transmitted for review upon completion of mapping in the San Fernando Valley.

3. Open-file report is in preparation to summarize the data base in support of seismic zonation studies in the Los Angeles Basin.

4. Tinsley and Hastorf prepared for transmittal to review a compilation of 850 carbon dates for the southern California area. The report includes a regional map of southern California (1:500,000) and a map of the Los Angeles basin showing locations of dated materials. Tables list the dates, their standard deviations, location and nature of the material dated, the laboratories at which the analyses were performed and cross-referenced bibliography. A brief text explains proper use of the data.

5. Les McFadden and John Tinsley have combined their independently derived data bases and have forged a preliminary soil chronosequence applicable to arkosic alluvial deposits across the Los Angeles basin. Laboratory analyses are in progress; early trends that clay content and iron concentration are important indices of the relative stratigraphic positions of pedons in the chronosequence.

6. Additional logs of boreholes have been incorporated into the data base employed to assess liquefaction susceptibility in the San Fernando Valley. Many 7.5' quadrangles have over 500 borehole logs the distribution of which provides a reasonable basis for identifying grain sizes susceptible to liquefaction.

Reports

McFadden, L. D., Tinsley, J. C. and Hendricks, D., A preliminary soil chronosequence for the tectonically and climatically controlled terraces and alluvial fans of the San Gabriel mountains and the Los Angeles basin, California (abs.): Director's approval received 6/7/79; submitted 10/3/79 to Cordilleran Section, Geological Society of America, Corvallis, Oregon.

FINAL TECHNICAL REPORT SUMMARY

Part 1 of Contract
No. 14-08-0001-16819

Tertiary and Quaternary fault history of the intersection of the Garlock and Death Valley fault zones, southern Death Valley, California.

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INVESTIGATIONS:

Geologic mapping was completed on photographs enlarged to a scale of 1:7,100 of an area of about 40 square miles where the Garlock and Death Valley fault zones intersect, along the north front of the Avawatz Mountains. The geology was compiled on a topographic base map at a scale of 1:24,000 from tracings of the field maps.

RESULTS:

The west-trending Garlock fault, expressed by a south-facing scarp and southwest-trending minor grabens south of it, appears to die out at its eastern termination near the Mule Spring fault. The Mule Spring fault trends slightly more southeasterly than does the Garlock fault and has had, as its principal movement, reverse movement up on the south. It has elevated bedrock, mainly diorite of the Avawatz Mountains, approximately 4,000 feet over Tertiary sedimentary rocks that contain clasts of diorite derived from the Avawatz Mountains. The western part of the Mule Spring fault is vertical to steeply south-dipping. It gradually flattens eastward to about 40°SW.

The Death Valley fault zone trends north-northwest in low hills that extend into Death Valley from the Avawatz Mountains. The zone consists of several branches in the low hills that give way southeastward to three branches along the north flank of the Avawatz Mountains. The three branches swing gradually more easterly as they cross the northern part of the Avawatz Mountains. They also change from a near vertical dip to a moderate then very low southwesterly dip. The faults cut progressively younger rocks southeastward as they flatten. Thus it appears that the branches of the Death Valley fault zone changes from right-lateral slip to the north to reverse slip (up on the south) at its southeastern trace.

Combined reverse slip on the Mule Spring fault and Death Valley fault zone appears to equal at least the elevation difference between the base and crest of the Avawatz Mountains, which exceeds 4,000 feet.

Tertiary sedimentary rocks between fault branches on the north flank of the Avawatz Mountains contain clasts of diorite derived from the Avawatz Mountains. Their presence precludes lateral offset along the fault zones of more than a few miles since the Tertiary rocks were deposited.

The most recent fault movement is along the grabens near the Garlock fault and along reverse faults along the southeastern part of the Death Valley fault zone. The grabens are in gravel that is next older than modern stream gravel. The reverse faults displace various rock units over some of the older gravel units of Quaternary age. Movement is progressively younger on branches of the Death Valley fault zone from south to north. The southeastern end of the fault zone cuts quaternary gravel that overlies it without interruption farther to the northwest.

Part 2(a) of Contract
No. 14-08-0001-16819

Time relations between faulting, volcanism, and fan development, south-central Death Valley, California.

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INVESTIGATIONS:

Field investigations consisted of seeking outcrops of andesitic ash-fall deposits expelled from a cinder cone near Shoreline Butte in south-central Death Valley offset by right-lateral movement along a branch of the Death Valley fault zone. The relations of the ash deposits to the Quaternary gravel deposits and faults was noted at each ash deposit.

RESULTS:

More than 10 ash-fall deposits were found, all within five miles of the cinder cone. The ash was deposited on fan gravel clearly Quaternary in age and subsequently was covered by a younger set of fans. It was eroded by shoreline activity during a stand of the lake at an elevation of approximately 200 feet.

Fan development has occurred since Pliocene time and has been accompanied by episodes of normal faulting, right-lateral faulting, and one episode of volcanism. Volcanism preceded the dessication of Lake Manly and normal and right-lateral faulting has occurred since volcanism. A K-Ar analysis made by Robert E. Drake yielded an age for the volcanic rock of 690,000 $\pm$ 20,000 years. It is not clearly established that faulting and volcanism have ceased in Death Valley.

Part 2(b) of Contract
No. 14-08-0001-16819

Rate of Cenozoic slip on normal faults, south-central Death Valley, California.

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INVESTIGATIONS:

The structural relations and clast content of Tertiary conglomeratic sedimentary rocks, lying at the west base of the Black Mountains in the vicinity of Smith Mountain were investigated. Clasts in conglomerate were compared with rock in potential source regions to determine the source area and measure the rate of slip on a normal fault beneath the Tertiary rocks. Samples of volcanic rocks were collected and processed to determine the age of the sedimentary rock. The rate of slip was calculated based on the age of the sedimentary rocks and the elevation difference of the front of the range.

RESULTS:

Clasts of volcanic rocks in the Tertiary sedimentary rocks at the base of Smith Mountain are similar in texture and composition to volcanic rocks that lie east of the ridge crest at Smith Mountain. The age of formation of the volcanic flow rocks range from 7 to 8.8 m.y. and the amount of slip on the normal fault that underlies the Tertiary sedimentary rocks is approximately 6,000 feet. The minimum rate of slip is calculated to be 1.2 feet per 1,000 years.

Earthquake Hazards Studies, Ventura basin and adjacent areas, southern California

9540-01615

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Investigations - (Yerkes)

1. Collected, integrated, and mapped surface and subsurface data bearing on degree and rate of deformation in the Ventura area, where a unique stratigraphically-controlled sequence of datable ashes and mollusks is present in an unusually thick late Pliocene-Pleistocene marine section.

2. Collected, integrated, and mapped surface and subsurface (marine geophysical and well) data on sections and maps to evaluate structure and deformation rates of the northwest Santa Barbara Channel-Point Arguello area.

(Sarna-Wojcicki)

3. Mapped, sampled, and analysed four Pleistocene ashes along north and south limbs of Ventura Avenue anticline, in continuing study aimed to provide age calibration for the Quaternary section exposed in this area (with K. R. Lajoie, J. W. Hillhouse, USGS, and J. Liddicoat, Lamont-Doherty).

4. Mapped uplifted late Pleistocene and Holocene marine terrace platforms and associated deposits; mapped shoreline angle of uplifted Holocene terrace platform (with K. R. Kajoie and G. Kennedy, USGS).

5. Mapped and measured ground breakage and ground disturbance associated with the M 5.7 August 6, 1979 Coyote Lake earthquake on the Calaveras fault (with R. J. McLaughlin, M. M. Clark, R. V. Sharp, D. H. Sorg, R. K. Mark, and D. G. Herd).

Results (Yerkes)

1. The deeply-dissected Ventura Avenue anticline north of the active Ventura fault exposes about 2.5 km of folded Pleistocene marine strata with age range estimated at 1.2×10^6 YBP; included are strata containing the type Hallian Stage with base at about 0.7×10^6 YBP, and the Wheelerian Stage, which in Hall Canyon ranges from about 1.8 to 0.7×10^6 YBP. A quantitative model suggests that deformation began about 550,000 YBP, attained average uplift-erosion rates of 16 mm/yr over the last 200,000 yr for the axial part of the anticline and tilt rate of about 1.5×10^{-6} rad/yr over the last 80,000 yr for the marine terrace platform that transgresses bedrock along the south flank of the anticline.

2. A unique, south-facing, continuous submarine escarpment 100 m high extends for more than 115 km from off Point Arguello to near Santa Barbara; it has a near-planar, near horizontal crest at about -100 m. It separates a narrow, structurally high near-shore bedrock bench from the sea/channel floor. Much of the escarpment is underlain by landward-dipping reverse faults: east-trending in the channel, and imbricate-tangential to the escarpment west and northwest of the channel. As derived from associated fault-plane solutions, slip on the channel segment is chiefly reverse to reverse-left-oblique, whereas that to the west appears on sparse data to be nearly pure left-lateral (east-west). The North Channel escarpment is inferred to be a fault-line scarp dating from before its planation about 16,000 YBP during a low stand of the sea. The near-shore bench and a 3-km segment of the escarpment have been deformed by later displacement on subsidiary reverse faults such as the South Santa Ynez. The combined long-term vertical uplift rate of marine terraces and the near-shore bench in the Point Conception-Gaviota area is about 4 mm/yr. In addition, comparison of 1900-1920 levels over the Ventura-Guadalupe geodetic profile shows more than 200 mm arching over the Point Conception-Goleta coastline; historical studies of the southern California uplift show that this pulse actually occurred during 1904-1914, for a rate greater than 20 mm/yr.

(Sarna-Wojcicki)

3. Previous work (see Sarna-Wojcicki, Semi-Annual Report, June 1978) has shown that six volcanic ashes, persistent time and stratigraphic markers, are present in the folded and faulted Quaternary marine section of the Ventura Avenue anticline north of the town of Ventura, and in the South Mountain area to the east. Four of these ashes have now been mapped along both the north and south limbs of the anticline, over a distance of 24 km. Stratigraphic relations between these ashes were previously inferred on the basis of partial, isolated sections and projections along strike, as well as from correlations of these ashes to the source area, the Long Valley-Mono Glass Mountain area east of the central Sierra Nevada, where stratigraphic relations and ages of three of the ashes are known. Recent field work shows that all four ashes are within a continuous stratigraphic section on the north limb of the anticline, supporting earlier correlations.

The four ashes, from oldest to youngest, are correlated with the "Bailey" ash (1.2 ±0.2 m.y.; Izett and others, 1974), the "Gray" ash (about 1.0 m.y.), the ash of "Mono Glass Mountain" (about 0.8 m.y.), and the Bishop ash (about 0.7 m.y.; Dalrymple and others, 1965).

The uppermost ash, the Bishop, is repeated and overturned above this section, where the Red Mountain fault is thrust southward over the north limb of the Ventura Avenue anticline. Involvement of this ash in the faulting shows that the Red Mountain fault has been active since 0.7 m.y. b.p. Offset of late Pleistocene marine terraces, and seismicity geometrically associated with this fault (Yerkes and Lee, 1979), indicate it is active at present.

4. Previous work (see Yerkes, Lajoie, Semi-Annual Reports of Dec., 1978) has indicated that uplift rates of late Pleistocene and Holocene marine terrace platforms along the coast west of Ventura have been rapid but relatively constant over approximately the last 45,000 years. Elevations of the emergent

Holocene terrace platform near Javon Canyon range from about 6 to 20 m, and radiocarbon ages for deposits on this terrace range from 1800 to 5500 years b.p. The oldest age of 5500 years, combined with estimated uplift rates of 6.6 mm/year calculated from uplift of a higher, 45,000-year marine terrace, suggested that the shoreline angle for the Holocene emergent terrace could be as high as 36 m if uplift rates were constant in late Quaternary time. Recent field work has shown that the Holocene (<5500 YBP) shoreline angle is at about 36 m above sea level, corroborating previous observations and giving identical uplift rates of 6.6 mm/year for both terraces.

5. Ground deformation and disturbance associated with the August 6, 1979 Coyote Lake earthquake on the Calaveras fault was less than expected for a M 5.7 earthquake, compared to other historic earthquakes of comparable magnitude. Fresh, irregular and en-echelon cracks with up to several mm of lateral spreading were found in paved roads crossing the Calaveras fault zone at several localities over a distance of about 28 to 30 km. Maximum right-lateral displacements of 5 mm with an equal amount of lateral spreading were measured in pavement of California Highway 152 about 4 km southeast of the epicenter. Relations between magnitude and displacement compiled from historic, world-wide data for strike-slip faults, as well as for faults of all types, suggest that average ground displacements for this magnitude are 10 to 40 times greater. The relatively deep hypocenter in relation to the magnitude of the earthquake may accout for the small surface displacements.

Reports

Yerkes, R. F., and Campbell, R. H., 1979, Stratigraphic nomenclature of the central Santa Monica Mountains, Los Angeles County, California: U.S. Geological Survey Bull. 1457-E, 31 p., pls.

Lajoie, K. R., Kern, J. P., Wehmiller, J. F., Kennedy, G. L., Mathieson, S.A., Sarna-Wojcicki, A. M., Yerkes, R. F., and McCrory, P. A., 1979, Quaternary shorelines and crustal deformation, San Diego to Santa Barbara: Geol. Soc. America, 92d Ann. Mtg., San Diego, CA, guidebook ____, 32 ms. p.

Herd, D. G., McLaughlin, R. J., Sarna-Wojcicki, A. M., Clark, M. M., Lee, W. H. K., Sharp, R. V., Sorg, D. H., Stuart, W. D., Harsh, P. W., and Mark, R. K., 1980, Surface faulting accompanying the August 6, 1979 Coyote Lake earthquake, [abs.,] American Geophysical Union 1979 Annual Meeting, Abstracts with Program.

Yermilin, V. I., Sarna-Wojcicki, A. M., and Chigaryev, N. V., 1979, Holocene deposits of the Pamir-Alay: Preliminary analysis of results of absolute age dating, in Collection of Soviet-American studies on Earthquake Prediction, "Donish" Publisher, Dushanbe-Moscow, v. 2, book 2, p. 178-188.

Southwestern Utah Seismotectonic Studies

9950-01738

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Investigations

1. Field studies in the Tunnel Spring Mountains, Millard Co., Ut., followed by major revision of a report on the late Cenozoic structural history of the area.

2. Organization of a conference on earthquake hazards along the Wasatch front and in the Reno-Carson City area held at Alta, Ut., 29 July - 1 August 1979, and preparation of a summary of the conference for internal distribution.

3. Preparation of report entitled, "Status of seismotectonic studies in southwestern Utah," for inclusion in the proceedings volume of the conference in (2) above.

4. Field measurement of profiles on the Bonneville shoreline, Cricket Mountains, Millard Co., Ut., for use as reference data to which profile data from faults in western Utah can be compared.

Results

1. Seventeen profiles on the Bonneville shoreline in the Cricket Mountains yield a regression equation of scarp height on maximum scarp slope angle of $y = -0.793 + 24.9x$ with a standard deviation of y about the line of 2.33.

2. The Bonneville shoreline in the Cricket Mountains is cut on alluvial fan surfaces that are probably more than 1×10^5 years old as judged from a qualitative assessment of the age of calcic soils developed on the surfaces. The alluvial fans extend across the Bonneville shoreline into the area of the ancient lake. They are well preserved (though slightly modified by lacustrine erosion) in the elevation interval between the Bonneville and Provo shorelines. These data indicate a lengthy period of desiccation of the Sevier Desert basin prior to the occupation of that basin by the last lake cycle--the Bonneville cycle.

Reports

Anderson, R. E. and Bucknam, R. C., 1979, Map of fault scarps in unconsolidated sediments, Richfield 1° x 2° quadrangle, Utah.

Seismic Hazards of the Hilo 7 1/2' Quadrangle

9550-02430

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Investigations

Damage in Hilo from past earthquakes appears to have been most severe on terrane underlain by ash, and mapping recently has concentrated on the distribution and thickness of ash deposits in and near the city. Thickness and character of the deposits was determined at as many localities as possible in the quadrangle. Appropriate outcrops were much less abundant than would be ideal; thus some of the information gathered was in adjoining quadrangles to the north and west of the Hilo quadrangle. These quadrangles are loci of current urban expansion of metropolitan Hilo.

Results

Ash deposits mapped in selected portions of the Papaikou, Akaka Falls, and Pi'ihonua quadrangles as well as within the northwest portion of the Hilo quadrangle show a general increase in thickness from west to east and north to south. The thickest section measured thus far is 7 m and the thinnest is 1 m. Severe weathering of the ash, which is subjected to an average of 140 in. of rainfall per year, has resulted in alteration of most, if not all, of the original constituents.

Underlying the ash are well-developed saprolites. They probably contain as much clay as the ash deposits and locally exceed the thickness of the ash deposits (as much as 10 m thick). The ash and saprolite are ubiquitous north of the Wailuku River, and have been found locally south of the river. Both areas seem to be particularly susceptible to ground shaking according to reports by residents. Additionally, the ash and saprolite are very susceptible to sliding along the deeply incised east-west oriented drainages of the area.

Reports

Isopach maps are being prepared which show the thickness of ash deposits, combined thickness of ash and saprolite, and degree of slope. The maps will be useful in determining susceptibility for landsliding and will be submitted in the MF map series.

Anchorage-Susitna Lowlands Earthquake Hazards Mapping

9310-02078

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Investigations

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

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

3. Initiated study of active faults with emphasis placed on increasing our knowledge of the Castle Mountain fault.

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

Results

1. Completed enough surficial/engineering geologic mapping so that a preliminary map of the entire study area can be prepared.

2. Several radiocarbon age determinations were made of organic samples collected from stratigraphic units equivalent to the Bootlegger Cove Clay and from overlying morainal deposits. The Bootlegger Cove Clay and equivalent units have been dated at approximately 14,000 years B.P., and the overlying morainal deposits at approximately 12,000 years B.P.

3. Several radiocarbon age determinations of samples from raised beach deposits and tidal bog sediments approximately one meter above present sea level give an average age of about 500 years B.P. indicating that within the last 500 years these coastal areas have been uplifted about one meter relative to sea level.

4. Obtained logs and soils analyses from approximately 2000 boreholes. These data, obtained from private, state, and federal organizations, have been catalogued in a card file and currently are being synthesized.

5. Completed synthesis of subsurface engineering soils data from the Government Hill area of Anchorage, and currently preparing report which will present systematic geologic descriptions of the Bootlegger Cove Clay unit, facies changes, and engineering characteristics.

Seismo-Tectonic Analysis of Puget Sound Province

9540-02197

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Investigations

1. Earthquake foci from the University of Washington Puget Sound microseismic net are being compiled at a scale of 1:250,000 for inclusion on the Seismo-tectonic map of the Puget Sound Region.

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

3. Bedrock geologic mapping of the Clear Lake Northwest orthophoto quad is underway as part of the compilaton of the bedrock geologic map of the Port Townsend 1:100,000 scale sheet.

4. A seismic ground response map of the 7-1/2' Seattle and adjacent eastern part of the Duwamish Head quadrangle is nearing completion and a study of potential liquefaction-induced ground failure for the Seattle-Bremerton area is underway.

5. A 12 station microseismic net is being installed along the west coast of the Olympic Peninsula to detect, locate and determine focal mechanisms of earthquakes west of Puget Sound to test the regional seismo-tectonic model and to evaluate the current seismic state of the Calawah Fault zone.

6. A detailed structural map depicting faults according to age of latest movement and fold axes is being compiled for the eastern Strait of Juan de Fuca. The structures shown on this map are being related to magnetic and gravity data and onshore geology.

Results

1. The subsurace distribution of major Quaternary lithologic units useful for seismic zonation in the Seattle area were obtained by the collection and analysis of geotechnical logs of boreholes from building sites and highway construction. Standard penetration values from similar depths appear unique on the average for several Quaternary lithologic units. Artificial fill, sandy alluvium, and some well-sorted glacial sand units have particularly low resistance to penetration. Much of the area suffering significant building damage during the 1965 Seattle earthquake is underlain by as much as 100 meters of these low resistance deposits.

2. Geologic mapping has revealed several previously unknown faults in Skagit and Jefferson Counties.

Reports

Whetten, J. T., Dethier, D. P., and Carroll, P. R., 1979, Preliminary geologic map of the Clear Lake NE orthophoto quad., Skagit County, Washington: U.S. Geological Survey Open-File Report 79-1466.

Seismotectonic Analysis Rio Grande Rift, New Mexico

9530-01556

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Investigations

1. Completed excavation, mapping, sampling, and backfilling of four exploratory trenches across the La Jencia fault, a major range bounding fault along the eastern margin of the Magdalena and Bear Mountains, central New Mexico.

2. Described, sampled, and analyzed 14 soil profiles (103 samples) and 64 sediment samples from the trench exposures for characterization. Soil samples were analyzed for complete grain-size, pH, organic matter, bulk density, and calcium carbonate content (see also L. A. Douglas: Soil Morphology and Fault Movement, Contract No. 14-08-0001-G-520, Rutgers University).

3. Measured 40 detailed topographic profiles across the scarp along segments of the fault. Also measured 11 profiles across the Cox Ranch fault near White Sands, New Mexico, for comparison.

4. Mapped trenches at 1:50 scale using a soil stratigraphic framework. Soils data (descriptive and quantitative) were used to estimate ages of faulted and unfaulted deposits, thus bracketing fault age and defining periods of pre-fault stability.

Results

1. The La Jencia fault persists almost continuously for 35 kilometers and has up to 6 meters of surface offset in juxtaposed deposits of early Holocene to middle Pleistocene age. There is no systematic increase in scarp height in the older deposits. This suggests the recent fault activity was preceded by a long (10^5-10^6 years) period of tectonic quiescence.

2. At any particular site along the fault the surface rupture was probably produced by a single fault event or several events closely spaced in time. There is no morphometric evidence of compound fault scarps.

3. The scarp-forming fault movements are middle(?) Holocene to latest Pleistocene in age along the full length of continuous surface rupture.

4. Movement along the fault has occurred in segments, the most recent activity being at the northern and southern ends and in the central portion. Earlier movements occurred on the intervening portions. This conclusion is independently based on both scarp profile analysis and fault chronologies developed from soil stratigraphic relations in the trenches.

5. The scarps may have been modified more rapidly than comparable scarps in Utah even though they are formed in similar parent materials under similar vegetative, topographic, and climatic conditions. Normalized 3-meter-high scarps of middle Holocene age have the same maximum scarp angles as the Drum Mountain faults of Bucknam and Anderson (1979, Geology, v. 7, no. 1, p. 11-14). An alternate conclusion is that the Drum Mountain faults are younger than previously thought.

Wasatch Front Surficial Geology

9550-01622
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Investigations

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

2. The compilation of the surficial geology of the northern segment has been completed, and that of the southern segment is underway.

3. The derivative map of physical properties of the surficial materials remains to be done.

Results

The project was active for 6 months of fiscal year 1979, during which time the following was accomplished:

1. Technical review was completed of the surficial geologic map of the northern segment. The map was approved by the Branch as an MF map in June 1979, and the map is now in DTRU.

2. In response to reviewers' comments, the scale of the mapping has been photographically enlarged from 1:125,000 to 1:100,000 to show better detail along the Wasatch mountain front. The revised scale is compatible with the publication scale of the Utah Geological and Mineralogical Survey, which will incorporate the result of this mapping into a compilation of surficial geology of a larger area.

3. Field evidence from this investigation indicates that previously used stratigraphic concepts are not applicable to this study. Rather than using map units based on the premise that there were several fluctuating lakes that rose and lowered to near dryness, this study has developed map units based on the concept that Lake Bonneville filled once and then lowered with pauses of now conspicuous shorelines. The surficial geologic map, in addition to being necessary for the compilation of the physical property map, supplements the stratigraphic studies underway by W. E. Scott (9530-02174).

4. Radiocarbon dates were determined on samples collected as part of this project and submitted in March 1979. A date of 10,920±150 B.P. (W-4395) was obtained on shells collected from humic layers about 9 m above the present

lake level. The deposits above the dated horizon accumulated in water when Lake Bonneville stood at the Gilbert shoreline, which is only 12 m above the present lake level. This date and the stratigraphic control on the overlying materials restricts any rise since that time to only 3 m above the shell-rich layer. This date agrees with those dates of others obtained earlier from Danger Cave (near Wendover, Nevada) and the Hooper Drain (near Ogden, Utah) that also call for a similar low lake level since about 9,000-10,000 years ago.

5. Results of laboratory analyses on samples from five test holes in materials potentially susceptible to liquefaction are being prepared for release as an open-file report.

6. In support of the project of W. W. Hays (9940-01919), 12 possible sites were selected for seismograph monitoring in Cache Valley, Utah.

7. Accompanied by R. W. Fleming, a very large landslide deposit was examined in an area of rapid urban development near Provo, Utah. The landslide was older than the highest shoreline of Lake Bonneville, and we concluded that urban development was unlikely to reactivate movement of the large landslide mass, although new landslides of smaller dimensions are likely.

Reports

Hays, W. W., Algermissen, S. T., Miller, R. D., and King, K. W., 1978, Preliminary ground response maps for the Salt Lake City area, Utah, in International symposium on microzonation, 2d, San Francisco, California, 1978, Proceedings: p. 498-508.

Hays, W. W., Miller, R. D., and King, K. W., 1978, Ground response in the Salt Lake City and Provo, Utah, areas [abs.]: Earthquake Notes, v. 49, no. 4, p. 15.

Alaska Geologic Earthquake Hazards

9310-01026

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Investigations

1. A study was made of uplifted shorelines in the Lynn Canal, Chatham Strait, Icy Strait, and Glacier Bay areas of southeastern Alaska to determine the amount and rate of uplift since the tidal bench marks were last surveyed in 1959 (Hicks and Shofnos, 1965).

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

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

Results

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

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

3. In the Icy Cape area there are three well-defined continuous Holocene marine terraces with beach angles at roughly 50-70', 100-120' and 200-240' that are cut into Pleistocene(?) fluvioglacial and beach ridge/lagoonal deposits. The highest terrace is locally covered by wood-bearing Holocene glacial deposits. The lowest terrace locally is mantled with younger beach deposits to 7' above present mean higher high water (MHHW) and marine glacial deposits containing abundant driftwood and mollusk remains that are as much

as 26.5' above present MHHW. Radiocarbon dating of wood, peat, and shells collected from the uplifted deposits should provide data on the emergence time-history of the terrace sequence in the Icy Cape area.

Reports

Page, W. D., Alt, J. N., Cluff, L. S., and Plafker, George, 1979, Evidence for the recurrence of large-magnitude earthquakes along the Makran coast of Iran and Pakistan: Tectonophysics, v. 52, p. 533-547.

Carlson, P. R., Plafker, George, Bruns, T. R., and Levy, W. P., 1979, Seward extension of the Fairweather fault, in Johnson, K. M., and Williams, J. R., eds., The United States Geological Survey in Alaska: Accomplishments during 1978: U.S. Geological Survey Circular 804-B, p.

Hudson, Travis, Plafker, George, and Rubin, Meyer, 1979, Tectonism and marine terrace development in the eastern Gulf of Alaska [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 3, p. 85.

Hunt, Susan, Plafker, George, and Hudson, Travis, 1979, Active fault map of Alaska: A progress report [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 3, p. 85.

Lahr, J. C., Plafker, George, Stephens, C. D., Fogelman, K. A., and Blackford, M. E., 1979, Interim report on the Saint Elias earthquake of 28 February 1979: U.S. Geological Survey Open-File Report 79-670, 35 p.

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

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

Quaternary Stratigraphy of the Wasatch Front

9530-02174
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Investigations

1. I conducted fieldwork along the Wasatch Front in the Cottonwood-Holladay area south of Salt Lake City, in the southern Utah Valley, and along the Wellsville Mountains north of Brigham City. Investigations included mapping faults, measuring fault scarps, and gathering stratigraphic information.

2. Samples of wood and charcoal were collected from critical stratigraphic positions and submitted for radiocarbon dating. Causes of inconsistencies in existing radiometric dates are becoming evident as new dates on more reliable materials become available.

3. On the flanks of the Cricket Mountains, southwest of Delta, stratigraphic and soil studies were begun with R. E. Anderson, M. N. Machette, and D. R. Muhs.

4. W. D. McCoy (University of Colorado) described about 110 stratigraphic sections in the Bonneville and Lahontan basins and collected about 200 samples of gastropods, pelecypods, ostracodes, and tufas for amino-acid studies, including isoleucine epimerization and natural hydrolysis of proteins. Modern materials were collected for pyrolysis experiments to determine reaction kinetics. Hopefully the technique will provide a reliable tool for correlating between widely separated exposures and perhaps for dating as well.

Results

1. Several estimates of tectonic slip rates on segments of the Wasatch Fault have recently been made for different intervals of time. Using offsets of latest Pleistocene and Holocene deposits, Woodward-Clyde Consultants estimated slip rates of about 0.8 to 1.8 m/Kyr. An average uplift rate of about 0.4 m/Kyr was obtained by Naeser, Bryant, Crittenden, and Sorenson of the USGS using fission-track ages of apatites. Offset datums of intermediate ages (10^5 to 10^6 yr) are needed to better assess the possibility of nonuniform rates of tectonic slip, which, in turn, would be reflected in variable recurrence intervals of surface-faulting events over time. Along the Wasatch Front, datums of this age are present only locally as relict surfaces of alluvial fans that lie above the Bonneville shoreline. Below the Bonneville shoreline, datums of this age are generally concealed by younger deposits, and are little exposed.

Recently, however, large gravel operations north of Big Cottonwood Creek are beginning to expose faulted deposits of the next-to-the-last lake cycle that are probably about 150,000 yr old. The zone of faulting here is about 0.5 km wide and consists of many breaks. Total offset of Bonneville-cycle and related deposits is about 8 m--an average of 0.5 m/Kyr. The older materials are displaced at least 16 m--a minimum rate of 0.1 m/Kyr. Some faults displace older sediments but not the overlying Bonneville sediments, and other faults displace both. However, excavations are not yet extensive enough near some faults to expose the older sediments so that the total amount of pre-last-lake-cycle offset is not known. If the rates of about 0.5 to 1.0 m/Kyr are valid over the past 10^5-yr interval, there should be about 75 to 150 m of displacement of these older deposits--much more than yet seen. As gravel operations proceed, hopefully more information will become available.

2. New exposures of deposits of the next-to-the-last cycle of Lake Bonneville (estimated age about 150,000 yr) indicate that the highest level attained by this lake was probably more than 65 m below the highest level reached by the last lake (Bonneville shoreline). In contrast, previous workers have presented interpretations for one to several lake rises that reached levels close to the Bonneville shoreline. The exposures are located north of the mouth of Big Cottonwood Creek and at the Point-of-the-Mountain near Jordan Narrows. At both localities, the older lake deposits consist of shore facies and display stratigraphic relationships that suggest they represent the highest lake rise of that cycle. If this interpretation is correct, an explanation for the greatly different levels is not apparent, but may involve a difference in the character of the two pluvials, a change in the altitude of basin divides, or a major change in the hydrology of the basin, such as the diversion of Bear River into the Bonneville basin as was suggested by R. C. Bright in 1963.

3. Initial investigations along the western flank of the Wellsville Mountains, north of Brigham City, revealed a fault history that is different from that of other areas along the Wasatch Front. A northward decrease in relief of the range and the distribution, height, and age of fault scarps along the range reflect a general northward decrease in the rate of tectonism during the late Quaternary. The data also suggest that the western flank of the Wellsville Mountains is composed of several fault segments of contrasting behavior. An 8-km-long segment at the southern end of the range near Brigham City contains evidence of recurrent Holocene activity and about 10 m or more offset of deposits of the last cycle of Lake Bonneville. An adjoining segment extending farther north about 8 km has evidence of less faulting of Holocene and/or latest Pleistocene age than the southern segment. For a few kilometers farther north, there is evidence for about 26 m of offset of an alluvial-fan surface that, based on soil development, appears to be about 150,000 yr old, but there is no evidence of post-Lake Bonneville faulting. The northernmost 11 km of the range front contains no faulted surficial deposits. Northward, the range terminates in a broad pass underlain by Tertiary rocks and the Malad Range north of the pass shows little evidence of late Quaternary faulting. These observations suggest that a transition from a more active portion of the Wasatch Fault in central Utah to a less active portion in northernmost Utah and southern Idaho occurs along the Wellsville Mountains.

4. Radiocarbon dates on wood from critical localities are aiding in understanding the causes of inconsistencies in ^{14}C dates obtained by others on carbonates. Wood from lagoonal sediments associated with a bar that was deposited during the transgression of the last lake cycle dated 19,700±200 ^{14}C yr B.P. (W-4421). This date and other dates on wood obtained in the 1960's define a curve of lake rise (up to an altitude about 100 m below the Bonneville shoreline) different from that obtained from previously dated carbonates. Radiocarbon dates on gastropods yield a curve of similar slope but displaced toward younger ages by about 1,500 to 2,000 yr. Dates on tufas are more widely scattered but show a trend about 1,500 to 3,500 yr younger than the gastropod dates and about 3,000 to 6,000 yr younger than wood dates. These differences indicate the magnitude of error for dates of this age that is probably due to contamination of carbonate shells and tufa by young carbon. Pending dates on wood and charcoal will better define the curve of the lake transgression at levels closer to the Bonneville shoreline.

STRATIGRAPHY OF PRE-VASHON QUATERNARY SEDIMENTS APPLIED TO THE EVALUATION OF A PROPOSED MAJOR TECTONIC STRUCTURE IN ISLAND COUNTY, WASHINGTON

Summary of Semi-annual Technical Report: August 8, 1979

USGS GRANT No. 14-08-0001-17753

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The main objective of this project is to conduct careful stratigraphic studies of Quaternary nonglacial sediments on Whidbey Island, Washington, in an attempt to "fingerprint" the Whidbey Formation. Once it is defined by sedimentary petrologic criteria, we hope to be able to correlate outcrops of the Whidbey Formation on Whidbey Island. The ultimate goal of this project is to then correlate stratigraphically equivalent units within the Whidbey Formation across a proposed major tectonic structure and determine the amount of vertical tectonic movement (if any) along the structure.

Detailed field work at the type section of the Whidbey Formation (Double Bluff) has revealed a complex relationship of nonglacial sediments. Radiocarbon dates provide evidence for the finite age of nonglacial sediments previously mapped as the Whidbey Formation (defined as $>$40,000 years B.P., and presumed much older). An erosional unconformity near the west end of the Double Bluff section separates older, fine-grained nonglacial sediments from younger, coarser-grained sediments. Radiocarbon dates, which bracket these younger nonglacial sediments, indicate that the entire process of erosion through the older sediments and deposition of the younger sediments occurred between 43,200 $\left(^{+3,200}_{-2,280}\right)$ and 22,210 $\pm$ 530 years B.P.

More evidence for nonglacial sedimentation during this time span has been obtained from the Useless Bay East section, where a series of radiocarbon age dates from peat beds date continuous nonglacial sedimentation between 39,210 $\binom{+1730}{-1420}$ and 28,910 $\binom{+690}{-630}$ years B.P. At Possession Point, a 30,470 $\binom{+1650}{-1370}$ year B.P. date from a peat clast incorporated in Possession drift provides a maximum age for the Possession glaciation. This date suggests that Possession drift at Possession Point was deposited by ice of the Fraser glaciation, probably less than 20,000 years B.P. Evidence for the youth of Possession drift at Possession Point, along with absolute age dates recording continuous nonglacial conditions from more than 43,000 to less than 23,000 years B.P., casts doubt on the Possession glaciation in the northern Puget Lowland.

These findings complicate the stratigraphic definitions of the Whidbey Formation, Possession drift, and Olympia-age nonglacial sediments. In the northern Puget Lowland, Whidbey Formation and Olympia-age sediments are defined as representing two separate and distinct nonglacial episodes, interrupted by the Possession glaciation. Proof that the nonglacial sediments on southern Whidbey Island represent one continuous nonglacial episode, with no intervening glaciation, will necessitate the redefinition of some Pleistocene stratigraphic units in the northern Puget Lowland.

Laboratory studies completed to date have generally failed to provide diagnostic characteristics that could be used to distinguish the Whidbey(?) Formation from other lithologically similar Pleistocene stratigraphic units. No differentiation can presently be made between the grain size composition of these stratigraphic units, since the range of textural variation is just as great within a unit as between units. The clay mineralogic composition of the Whidbey Formation is highly variable, and is similar to other nonglacial sediments on Whidbey Island. Preliminary results from heavy mineral analyses suggest only minor heavy mineral compositional variations between the Whidbey Formation and other Pleistocene stratigraphic units. The lack of contrast between younger and older units is probably a result of reworking of the same materials in similar depostional environments. More work needs to be completed before positive conclusions can be drawn. More sedimentary petrologic studies are presently being performed to verify the above findings.

Geologic Mapping of the Vista and Steamboat 7 1/2-Minute Quadrangles, Nevada

14-08-0001-17774

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Investigations

1. Geologic mapping will provide information on: 1) the distribution and physical properties of the Quaternary units based on their lithostratigraphic and sedimentologic patterns: and 2) the location and approximate age of last movement of faults which cut Quaternary deposits.

2. Trenching will provide detailed information on the nature of the fault zones and aid in the determination of the number of repeated movements. Sites will be selected to optimize the potential of obtaining material for absolute (C^{14}) or relative dating (Tephra).

Results

1. Potentially liquefiable deposits are flood-plain and lacustrine deposits consisting of interbedded silt, fine sand and minor peat, which underlie the lowest portions of the Truckee Meadows in the Vista and Steamboat Quadrangles. The mapped distribution of these deposits indicates they occupy 5 km^2 (2 mi^2) in the northwest corner of the Steamboat Quadrangle and 13 km^2 (5 mi^2) in the southwestern portion of the Vista Quadrangle. These materials are highly compressible and have low shear strength. Seismic velocity measurements in the adjoining Reno and Mt. Rose Quadrangles indicate these deposits have low shear wave velocities and when these are combined with the low bulk densities the calculated seismic coefficient results in the lowest values for deposits in the Truckee Meadows.

2. The most widely distributed Quaternary deposit of the two quadrangles is fine-grained alluvium which appears to have been deposited contemporaneously with the flood-plain and lacustrine deposits, mentioned above. These deposits cover approximately 26 km^2 (10 mi^2) and consist of silty very fine to medium sand, fine to medium sand and sandy silt with thinly interbedded sandy pebble gravel. The deposits occupy areas of low relief between the alluvial fans and the flood-plain lacustrine deposits.

3. Other unconsolidated Quaternary age deposits in the Truckee Meadows are alluvial fan deposits which represent the coarser equivalent of the fine-grained alluvium (described in 2 above). Eolian sand has been deposited in small isolated patches along the west face of the Virginia Range. Small closed basins within the Virginia Range are filled with fine-grained alluvium of unknown thickness and may represent only shallow deposits of unconsolidated material. Coarse outwash deposits of Donner Lake (Illinoian) age occur as small isolated highs in the southern portion of the Steamboat Quadrangle near the Steamboat Hills and in the west-central portion near the Huffaker Hills.

Tahoe age (Wisconsian) outwash has not been mapped in the Steamboat Quadrangle but, has been identified in the Truckee Meadows portion of the Vista Quadrangle to the north.

4. The western half of the Vista Quadrangle consists of Pleistocene alluvial fan deposits and Holocene-Pleistocene valley fill alluvium. The Pleistocene alluvial fans are moderately eroded, unconsolidated gravelly muddy coarse sand and sandy granule gravel. Soils on these alluvial surfaces are argillic and duric. These deposits are gradational to older valley fill alluvial remnants which consist of unconsolidated, moderately to deeply eroded, muddy very fine sands of Pleistocene age. Youngest Valley fill alluvial deposits are unconsolidated sands and sandy mud, which are covered by cambic soils suggestive of mid-Holocene age.

Overall, the Spanish Spring Valley area of the Vista Quadrangle appears to be one of limited Holocene deposition, since alluviation is confined to active drainage sources, and side slope alluvial fan deposits are of pre-Holocene age.

5. Mapping completed to date indicates that deposits of Quaternary age are cut by faults in several localities; 1) along the eastern margin of the Steamboat Quadrangle outwash of Donner Lake age is cut by several faults; 2) faults associated with the range-bounding fault along the front of the Virginia Range offset Quaternary age alluvial fan deposits that may be as young as Holocene; 3) near the northwest corner of the Vista Quadrangle where late Pleistocene alluvial fans have been displaced.

6. Sites for trenching are being evaluated based on apparent recency of faulting and accessibility. Several areas have been tentatively selected based on air photo interpretation. These areas are located in secs. 11 and 14, T19N,R20E in the Vista Quadrangle. Tentative trenching sites in the Steamboat Quadrangle include secs. 23, 26 and 34, T19N,R20E and secs. 3, 11 and 14, T18N,R20E.

Trenching will take place during the second half of the program along with completing the geologic mapping in the Vista Quadrangle.

Tectonic Tilt Measurements Using Lake Levels

9950-02396

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Investigations

Water levels of 12 large lakes were referenced at three locations around each lake in order to re-establish an array to monitor regional tectonic tilt in the region of southern Alaska from the central Alaskan Peninsula to the Yukon Territory. Many of these locations were originally established in 1964 and referenced in 1966; however, some reference marks were of questionable stability and some have been destroyed. In the summer of 1979 multiple benchmarks on bedrock or large boulders back of the ice-shove line were established at each location to allow future verification of local benchmark stability and the validity of tilt measurements. Lake levels were recorded simultaneously for several days to eliminate short-period and daily fluctuations. The re-established array consists of the following lakes: Alaskan Peninsula (Iliamna, Naknek, and Kontravishuna Lakes); Kenai Peninsula (Kenai, Skilak, and Tustamena Lakes); Chugach Range (Tazlina, Klutina, Eyak, and Bering Lakes); Southwestern Yukon Territory, Canada (Kluane Lake).

Results

Preliminary 1979 comparison with the 1966 water-level referencing indicates no significant tilt in 13 years over the 50-km triangular array of bedrock benchmarks of eastern Iliamna Lake. 1966 measurements were reproduced to within 4 mm or 0.08 microradians. 1979 comparisons with the 1966 referencing to measure tilt across the other lakes are questionable because there is no way of checking local stability of single, reference benchmarks not set in bedrock. Further analysis for consistency of tilt and utilization of other level data may remove some of these uncertainties. Continuous recordings from Eyak and Bering Lakes are being collected in November 1979 and will be analyzed for short-term tilt events. The Alaskan array and sites established in 1978 on Utah Lake, Bear Lake, and Hebgen Lake in the Intermountain seismic belt of Utah, Idaho, and Montana are being fully documented to facilitate future re-occupation.

Late Tertiary and Quaternary Shoreline Datum Planes and Tectonic Deformation in the Southeastern United States

9590-00881

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Investigations

1. Late Tertiary and Quaternary correlation and dating methods: a. Completed South Carolina ostracode biostratigraphic assemblage zonation; b. completed initial biochronologic investigation of planktic foraminifers and calcareous nannoplankton; c. completed initial biostratigraphic and climatic pollen study; d. continued work on molluscan zonation, computer drawn relief diagrams and shoreline map; e. obtained uranium-disequilibrium series ages on late Quaternary corals.

2. Using these methods we: a. investigated the age and elevation of early Pliocene scarps from Virginia, North and South Carolina; b. correlated Quaternary sea levels, emphasizing those in the Cape Fear Arch region; c. compared late Quaternary Coastal Plain climatic and sea level records to deep sea isotopic, lithologic and faunal chronology and to uranium series terrace chronology of Barbados and New Guinea.

Results

1. The Orangeburg (=Citronelle) (S.C.), Coats (N.C.) and Thornburg (Va.) Scarps constitute a highly dissected paleo-shoreline last occupied by a major early and late(?) Pliocene transgression as evidenced by marine deposits seaward of the scarps which can be correlated throughout the study area. Toe elevations range from about 62 to 85 m and record relative sea level positions too high to be accounted for solely by a glacio-eustatic sea level rise. Final regression, however, from these scarps between 3.0 and 2.5 m y (million years) may represent a response to well documented intense hemispheric cooling and hence regression may have been partially caused by glacio-eustatic effects. Post 3.0 to 2.5 m y relative uplift of approximately 40 to 60 m is inferred to explain the present elevations of these scarps.

2. Pollen studies show that: a. early and late Pliocene, and early, middle and late Pleistocene floras were distinctly modern in composition, remarkably similar to each other, and indicate humid, subtropical to warm temperate climates characteristic of interglacial intervals. Environmental and resulting vegetational changes comparable to those known for the late Wisconsinan glacial-interglacial interval have not been recognized in Pliocene and pre-Wisconsinan Pleistocene marine deposits strongly suggesting these onshore deposits represent glacio-eustatic high stands of sea level deposited during interglacial intervals. b. Pterocarya, a minor but significant element in Pliocene floras, became extinct in the U.S. at about the Pliocene-Pleistocene boundary and only very rarely are reworked grains found in Pleistocene sediments. It is thus a useful biostratigraphic index taxon in the Southern Coastal Plain.

3. The following molluscan zones have been named and can be recognized over large portions of the southern Atlantic Coastal Plain: Chesapecten jeffersonius-C. madisonius

Interval-zone, Chesapecten madisonius-Noetia limula Interval-zone, Noetia limula-Glycimeris subovata Interval-zone, Glycimeris subovata-Anadara ovalis Interval-zone, Anadara ovalis-Anadara brasiliana Interval-zone and Anadara brasiliana Range zone.

4. Initial ecostratigraphic ostracode data, pollen analyses and uranium series dates on coral indicate middle and late Pleistocene relative high stands of sea level and interglacial or near interglacial climates at about 500,000-400,000; 200,000-180,000; 125,000 and 80,000 to 70,000 yr B.P., which can tentatively be correlated to deep sea oxygen isotope stages 13, 7, 5e and 5a, respectively. Although these Coastal Plain high stands correspond to hemispheric warm periods when sea level was high relative to those of glacial times, deep sea isotopic and faunal data, and uranium series dates on coral terraces suggest that only at about 125,000 yr B.P. was sea level above (+2 to +10m) that of the present MSL (mean sea level). For example, estimates of global sea level 82,000 yr B.P. from 13 m to 43 m below present MSL contrast sharply with preliminary Coastal Plain data indicating correlative sea level about 2 to 6 m above present MSL. Hence to explain our preliminary findings, either our dating methods and climatic data are not accurate enough, current ideas of Quaternary sea levels need reassessment, or post-depositional uplift has altered the original position of late Quaternary deposits. We are obtaining additional faunal and floral material and uranium series dates and are critically examining the published late Quaternary sea level data as well as our own to resolve these problems.

In summary, two major trends are emerging in our study. First, southern Atlantic Coastal Plain marine transgressions correspond to climatically warm, probably interglacial, intervals and thus signify glacio-eustatic sea level rises. However, sea level elevations reached during these warm intervals cannot be explained solely in terms of glacio-eustatically induced sea level fluctuations as evidenced by independently derived estimates of global sea level. A local tectonic component appears to have altered the original positions of some marine deposits and their associated geomorphic features. In general, older marine features were uplifted to progressively higher elevations than younger ones. We are currently trying to extract this tectonic component from the glacio-eustatic record and to estimate the magnitude and rate of net uplift during the last 5 m y.

Reports

Cronin, T.M., 1979, Eustacy, tectonism and the correlation of the southeastern Atlantic Coastal Plain Pliocene and Pleistocene marine deposits (abs.): Geological Society of America Abstracts with Program v. 11, no. 7, p. 407.

Cronin, T.M., 1979, Late Pleistocene marginal marine ostracodes from the southeastern Atlantic Coastal Plain and their paleoenvironmental interpretations: Geographie Physique et Quaternaire v. 33, no. 2, p. 121-173.

Cronin, T.M., in press, Biostratigraphic correlations of Pleistocene marine deposits and sea levels, Atlantic Coastal Plain of the southeastern United States: Quaternary Research.

Blackwelder, B.W., Late Wisconsinan and Holocene tectonic stability of the U.S. Mid-Atlantic Coastal Region. (Director's approval 9/12/79, for submission to Science).

Seismotectonics of Northeastern United States

9950-02093

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Investigations

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

2. A program to complete the gravity coverage of Pennsylvania continued and is now nearly complete.

Results

1. A preliminary version of the gravity map of Pennsylvania was exhibited (ref. 1).

2. An average elevation map of the conterminous United States was produced (ref. 6).

3. Several regional cross-trending gravity features were identified from a new regional gravity map of New York and Pennsylvania and their relationship to seismicity explored (ref. 3, 4, 8).

4. It was noted (ref. 7) that some of the aseismic regions of the eastern United States exhibit geologic conditions which tend to suppress shallow earthquake activity (e.g. geopressured zones, bedded salt, pre-existing bedding-plane thrusts, and the like). Cautions are expressed that the historical seismicity, based largely on felt reports, may not adequately reflect the stress regime at depth because of decoupling or seismic slip near the surface.

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

Reports

Diment, W. H., 1979, Geology and geophysics of geothermal areas, in Kestin, J., ed., A sourcebook on the production of electricity from geothermal energy: Washington, D.C., U.S. Government Printing Office, (in press).

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

Diment, W. H., and Urban, T. C., 1979, An average elevation map of the conterminous United States: U.S. Geological Survey Map (in review).

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

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

Nathenson, M., Urban, T. C., and Diment, W. H., 1979, Approximate solution for the temperature distribution caused by flow up a fault and its application to temperatures measured in a drill hole at Raft River geothermal area, Cassia County, Idaho: Geothermal Resources Council Transactions, v. 3.

Diment, W. H., 1980, Significance of the aseismic regions of the eastern United States: Geological Society of America, Abstracts with Programs, v. 8, (submitted).

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

Tectonic History of Eastern Ozark Uplift

9530-01930

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Investigations

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

2. Prepared 90 samples from subsurface material for paleontological examination.

3. Completed revision of report on the stratigraphy and structure of sediments above the Newport pluton of northeastern Arkansas.

4. Prepared a regional cross section showing the attitude of rock units in the upper Mississippi Embayment in an area where interpretations of seismic data are being made.

5. Revised field maps of the Newport area, Arkansas.

Results

1. The calcareous lower part of the Upper Cretaceous and Paleocene sequence of the Newport region, Arkansas, arches across a buried uplift that has been outlined by test-drilling in the southeastern part of the area. In crossing the 120-meter-high structure the calcareous unit thins to less than 1/3 of its 100 meter thickness around the uplift. In order to learn more about the nature of that thinning, representative samples were picked from drill cuttings and submitted for paleontological analysis. Preliminary results indicate that fossils representative of both Maastrichtian and Danian ages are present and that the possibility of establishing the date or dates of uplifting are good.

2. Remnants of Upper Cretaceous and lower Tertiary deposits northwest of the edge of the Mississippi Embayment of northeastern Arkansas rarely are preserved in sequences that show more than part of two units at any given locality. Even where the contact of the two units is exposed, their relationship generally is puzzling, yielding little hard evidence of their depositional relationship. Deposits of upland gravel overlie and protect remnants of Upper Cretaceous marine sand and clay throughout a broad area, suggesting that both units were spread across the area in extensive layers that did not have a channeling relationship. The gravel also overlies silicified remnants of Paleocene limestone in the upland area and, at the edge of the embayment where the sequence has been protected, the gravel overlies unaltered Paleocene limestone. Apparently the present limit of the limestone also is the limit of protection from chemical erosion. If so, the limestone may have extended regionally between the gravel and the underlying sand and clay until sub-gravel solution removed most of it. In that position the limestone would have protected the underlying Upper Cretaceous sequence while the

gravel was being transported. All three of the depositional units were in place prior to culmination of the uplifting associated with the Newport pluton and, therefore, establish a limit for the maximum possible age of that activity.

Reports

Glick, E. E., 1979, Post-Paleocene uplift along the northwestern edge of the Mississippi Embayment of northeastern Arkansas (abs.): Abstracts with Programs, South-Central Section of the Geological Society of America 13th Annual Meeting, Mountain View, Arkansas.

Hendricks, J. D., and Glick, E. E., 1979, A crustal model of the Newport pluton derived from geological-geophysical studies (abs.): Abstracts with Programs, South-Central Section of the Geological Society of America 13th Annual Meeting, Mountain View, Arkansas.

Eastern U.S. Seismicity and Tectonic Studies

9950-02303

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Investigations

1. Acquisition of 250 km of seismic reflection profiles on the New Madrid region was completed in May 1979; data processing was completed in August 1979. Geophysical Services Inc. (GSI) was the contractor. M. D. Zoback, A. J. Crone, D. P. Russ, and S. R. Brockman are co-investigators.

2. Acquisition of 140 km of seismic reflection profiles in the Charleston, South Carolina, region was completed in June 1979; data processing was completed in November 1979. GSI was the contractor. The work was jointly funded by the Nuclear Regulatory Commission. J. C. Behrendt and H. D. Ackermann are co-investigators.

Results

1. Profiles in the New Madrid region show excellent, continuous reflections from contacts of Eocene/Paleocene, Paleocene/Late Cretaceous, and Late Cretaceous/Paleozoic rocks. Locally continuous reflections are seen high in the Eocene section. Reflections from below the Paleozoic surface are seen only on two profiles. Highlights of the results include:

   a. A major fault zone was found in northeastern Arkansas that is coincident with the main northeast-striking seismic zone. The fault zone is 9 km wide and vertically displaces Paleozoic rocks a cumulative total of about 1000 m. The top of the Paleozoic rocks and younger horizons have a cumulative vertical displacement of about 50 m across the fault zone.

   b. A northeast-striking horst and graben system was found in the Ridgley, Tennessee, area. The system is subparallel to patterns of overlying surface deformation suggesting that structural elements in the system have been active during the Late Holocene. The main graben is bounded on the southeast by a fault with about 80 m of post-Middle Eocene vertical displacement. An intrusive body of igneous rock apparently underlies the axis of this graben. Intrusion of the igneous body has caused doming of overlying Mesozoic and Tertiary rocks. The graben, when projected to the northeast, passes under Reelfoot Lake.

2. Profiles in the Charleston region show several excellent reflectors that can be correlated over most of the region. The strongest reflector is associated with the top of the basalt, which was encountered at a depth of about 750 m in the Clubhouse Crossroads coreholes. Highlights include:

a. Offsets of about 50 m on three profiles can be correlated to define a northeast-trending fault zone that passes through the cluster of seismicity near Summerville, South Carolina.
b. Reflections can be seen below the top of the basalt that will yield insight concerning the Triassic/Jurassic basin that underlies the seismic region.

Reports

Hamilton, R. M., and Zoback, M. D., 1979, Tectonic deformation of the northern Mississippi embayment as revealed by seismic reflection profiles: Preprints of the Research Conference on Intra-Continental Earthquakes, Ohrid, Yugoslavia, p. 10-11.

Behrendt, J. C., Hamilton, R. M., and Ackermann, H. C., in press, Seismic reflection profiles in the area of the Charleston, South Carolina, earthquake: Earthquake Notes (Abstract of talk to be given at the Eastern Section Seismological Society of America meeting).

Zoback, M. D., Hamilton, R. M., Crone, A. J., Russ, D. P., and Brockman, S. R., in press, Major fault zone associated with the main New Madrid seismic trend shown by seismic reflection profiling: Earthquake Notes (Abstract of talk to be given at the Eastern Section Seismological Society of America meeting).

Behrendt, J. C., Hamilton, R. M., and Ackermann, H. D., in press, Multichannel seismic reflection profiles in the Charleston, South Carolina, area: EOS, (Abstract of talk to be given at the fall American Geophysical Union meeting).

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

Zoback, M. D., Hamilton, R. M., Crone, A. J., Russ, D. P., and Brockman, S. R., in review, Recurrent intraplate tectonism in the New Madrid seismic zone, (Article prepared for submission to "Science").

Tectonic Framework of the New Madrid Seismic Zone from Geophysical Studies

9730-01035

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Investigations

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

2. Conducted a detailed magnetic survey using a truck-mounted magnetometer for the purpose of delineating small magnetic bodies that may be related to seismicity in the embayment.

3. Initiated an aeromagnetic survey in eastern Arkansas encompassing an area of about 9,000 square miles.

Results

1. Interpretation of the aeromagnetic data suggests a complex tectonic evolution of the upper Mississippi Embayment region. As previously reported, a major tectonic event involving the development of a large graben or rift zone occurred in late-Precambrian or early Paleozoic time. New information suggests that the graben developed along a boundary or suture separating contrasting basement rock types. The graben, having a structural relief of 1.6 to 2.6 km, formed where tensional stresses caused the crust to fail by brittle fracture and shear. Subsequent crustal thinning and partial mealting of the crust led to plutonism and possibly volcanism. However, this magmatism occurred hundreds of millions of years after formation of the structural graben. The available magnetic data also suggest that the rift zone terminates northward in western Kentucky and southern Illinois, a region characterized by intense Paleozoic igneous activity and faulting.

2. The graben noticeably contains the area of principal seismicity in the upper Mississippi embayment. Also, the epicentral line of the 1811-1812 New Madrid earthquake series lies within the geographic limits of the graben. A linear trend of epicenters strikes northeast along the graben's axis and then abruptly changes direction to slightly west of north at the intersection of the graben with the Pascola arch. This trend change may be intimately related to series of inferred igneous masses emplaced along the axis of the graben. These intrusions may have cemented the associated faults in such a manner as to influence the distribution of stress. Strain related to present-day earthquakes would then follow structural features of less resistance such as the juncture of the Pascola arch and the graben.

3. Preliminary results from the truck magnetic survey indicate the presence of numerous 20-60 gamma anomalies having widths between 1,000-4,000 feet. Because the associated sources are thought to be shallow dikes or sills, the results may indicate a relationship between faulting and dike-injection. In other words, shear failures may occur along oblique planes within a distribution of dikes.

Reports

Hendricks, J. D., and Hildenbrand, T. G., 1979, Aeromagnetic map of northeast Arkansas: U.S. Geological Survey, Open-file Report 79-1208.

Hildenbrand, T. G., Kane, M. F., and Hendricks, J. D., 1979, Structural control of upper Mississippi Embayment seismicity inferred from analyses of aeromagnetic and gravity data (abs.): Geol. Soc. America Abs. with Programs, v. 1, no. 2, p. 149.

Hildenbrand, T. G., Kucks, R. P., Cordell, L., and Kane, M. F., 1979, Simple Bouguer gravity map of the Rolla 1° by 2° quadrangle, Missouri and Illinois: U.S. Geological Survey, Open-file Report 79-1192.

Hildenbrand, T. G., Kucks, R. P., Hendricks, J. D., and Kane, M. F., 1979, Simple Bouguer gravity map of the Poplar Bluff 1° by 2° quadrangle, Arkansas and Missouri: U.S. Geological Survey, Open-file Report 79-1181.

_____, 1979, Simple Bouguer gravity map of the Memphis 1° by 2° quadrangle, Arkansas and Tennessee: U.S. Geological Survey, Open-file Report 79-1182.

Hildenbrand, T. ., Kucks, R. P., and Kane, M. F., 1979, Simple Bouguer gravity map of the Blytheville 1° by 2° quadrangle, Tennessee and Arkansas: U.S. Geological Survey, Open-file Report 79-1180.

_____, 1979, Simple Bouguer gravity map of the Dyersburg 1° by 2° quadrangle, Kentucky, Missouri, and Tennessee: U.S. Geological Survey, Open-file Report 79-1183.

_____, 1979, Simple Goubuer gravity map of the Paducah 1° by 2° quadrangle, Illinois, Kentucky, and Missouri: U.S. Geological Survey, Open-file Report 79-1179.

Hildenbrand, T. G., Kucks, R. P., Kane, M. F., and Hendricks, J. D., (in press), Aeromagnetic map and associated depth map of the upper Mississippi Embayment region: U.S. Geological Survey, MF map.

Johnson, R. W., Hildenbrand, T. G., Haygood, C., Kunselman, P. M., and Hinze, W. J., 1979, Magnetic anomaly map of the greater New Madrid seismic zone (abs.): American Geophysical Union Midwest Section Meeting Abstracts and Programs, Columbus, Ohio, p. 7.

O'Leary, D., and Hildenbrand, T. G., (in press), Structural significance of lineament and aeromagnetic patterns in the Mississippi Embayment: Proceedings of the 3rd International Conference on Basement Tectonics.

Bedrock Geology of Three Boston Area Quadrangles

9550-02475
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Investigations

1. Bedrock mapping completed for three Boston area quadrangles (Boston North, Boston South, Newton, Massachusetts).

Results

1. Major faults trend east-west to east-northeast. This breaks the Boston Basin into a series of long narrow slices, each of which has characteristic structure and to a lesser extent, stratigraphy. Many of these faults may represent movement of the basin faults that formed structural framework of the original depositional basin. These faults generally contain diabase dikes that were intruded at a later date.

2. On the north side of the sedimentary Boston Basin there is a horst block. The bounding fault on the south side of this block is the so-called Northern Boundary Fault of the Boston Basin, a low-angle thrust dipping north. The north side of the horst is a high-angle fault that extends for at least 20 miles and contains two sharp, nearly right-angle bends (the Walden Pond fault). To the north of this fault lies the terrain of Salem gabbro-diorite and alkalic granite.

3. All of these faults, with the probable exception of the Walden Pond fault, are offset by a north-south fault system. Displacement on these faults is comparatively small and generally in a left-lateral sense. One of these faults cuts across the entire width of the Boston Basin.

4. In addition, the rocks of the entire area are broken by a dense network of small faults with no known preferred orientation.

Reports

Kaye, C. A., 1979, Engineering geologic framework of the Boston Basin: Preprint No. 3602, National meeting of the American Society of Civil Engineers, Boston, Massachusetts, April.

Kaye, C. A., and Zartman, R. E., 1979, A late Proterozoic Z to Cambrian age for the stratified rocks of the Boston Basin, Massachusetts, U.S.A.: Virginia Polytechnic Institute and State University (in press).

Quaternary Stratigraphy and Bedrock Structural Framework of Giles County, Virginia

9510-02463

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Investigations

1. Surficial deposits are being studied by Hugh Mills as a means of identifying fault offsets or other movements that may be related to the relatively high earthquake incidence in this area. A map of terraces along the New River, which bisects the county from north to south, is being prepared; further studies will attempt to date and correlate these terraces. Locally-derived unconsolidated surficial deposits are also being examined, and are expected to contribute to an understanding of the late Tertiary and Quaternary history of the area.

2. The detailed structural geology of this area, which is in the western part of the folded and faulted Appalachians, is being compiled in order to determine any possible relationship to modern seismicity, and to provide a framework for analysis of data from a seismograph network currently being operated by G. A. Bollinger at nearby VPI&SU. Structural information is being obtained by means of reconnaissance and detailed mapping, inspection and sampling of fault zones, and compilation of previous published and unpublished mapping.

Results

1. The map of New River terraces is about half completed. Delineation and correlation of distinct levels of terrace formation which would suggest episodic, perhaps tectonic, changes, cannot yet be made. Mapping of an area of locally-derived surficial material west of Mountain Lake is essentially complete, and provides evidence of topographic inversion, in which former hollows are converted through time to topographic noses. Frost heave is indicated in some boulder deposits, which suggests that they are relicts of a glacial climatic regimen. No direct evidence of tectonic activity has yet been found.

2. Analysis of the structural setting has followed two courses. The first, detailed examination and mapping of specific structural features in Giles County, has provided some refinement of the previous versions of the structure, but has yielded no evidence yet of post-Paleozoic movements. The second, regional structural synthesis, is focused on the location of Giles County within a critical area of the folded and faulted Appalachians, the junction of the southern and central Appalachians, a locus of significant changes in deformational style, particularly the relationship of thrust faulting to folding. Preliminary interpretation of published maps and field reconnaissance suggest that folds of the central Appalachians terminate under or are deformed by thrust faults and folds of the southern Appalachians, which were thus presumably emplaced later.

Northeastern U.S. Seismicity and Tectonics
9510-02388
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Investigations

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

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

Results

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

2. Continuous core drilling at selected points along the Ramapo fault show that the fault dips steeply southeast; 75^{o} SE at Stony Point and New York, 60^{o} SE at Ladentown, New York. A core hole is currently in progress at Bernardsville, New Jersey, site of the March, 1979 earthquake.

3. Trenching of the surficial deposits at the Stony Point site showed that faulting on the border fault does not extend into Pleistocene till immediately overlying the fault. Additional coring and trenching is currently in progress.

Reports

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

Mississippi Valley Seismotectonics

9950-01504

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Investigations

1. Geomorphic studies to characterize and determine the significance of surface deformation in the vicinity of New Madrid, Missouri, continued. The surface deformation was analyzed in light of subsurface deformation interpreted from seismic reflection profiles. The distribution of modern earthquake epicenters was compared to the patterns and timing of Holocene deformation.

2. Structural and stratigraphic interpretations were made of 250 km of seismic reflection profiles that were run in various parts of the upper Mississippi embayment. The studies were primarily concerned with structural styles, tectonic history, and the geologic and tectonic significance of intrusive bodies. R. M. Hamilton, M. D. Zoback, and S. R. Brockman are co-investigators.

3. Geological and statistical studies were conducted to characterize the structural configuration of the buried Paleozoic surface in the seismically active area between Ridgely, Tennessee, and New Madrid, Missouri. Trend-surface analyses were made using data interpreted from seismic reflection profiles. Residuals to the trend-surfaces were examined for structural significance.

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

5. Trend-surface studies of the configuration of Pleistocene and Holocene fluviatile terraces in the Mississippi Valley continued.

Results

1. The most striking surficial structure in the vicinity of New Madrid, Missouri, is the Lake County uplift, an elongate composite feature that is associated with faulting and modern seismicity. The structure upwarps the Mississippi River valley as much as 10 m in parts of northwestern Tennessee, southeastern Missouri, and southwestern Kentucky. The composite nature of the uplift is apparently the result of the reactivation of several ancient subsurface structures during earthquakes. Lake County uplift can be subdivided

into the Tiptonville dome, Ridgely Ridge, and the southern part of Sikeston Ridge. Most of Tiptonville dome formed between 200 and 2,000 years ago. Additional uplift deformed the NW and SE parts of the dome during the 1811-1812 New Madrid earthquakes. Much of Ridgely Ridge appears to be older than Tiptonville dome, but geomorphic evidence suggests that it is younger than 6,000 years B.P. About 75 percent of the microearthquakes recorded between 1974 and 1978 in the general region between Ridgely, Tenn., and New Madrid, Mo., fall within the area of the Lake County uplift. Most of the earthquakes are concentrated along the northwestern edge of Tiptonville dome and in the vicinity of Ridgely Ridge. Fault-plane solutions, trends of modern seismicity, and the orientation of the modern stress field suggest that the uplift may be primarily the result of vertical strain that was produced by horizontal compression in a region between two en echelon strike-slip faults.

2. Interpretations of seismic reflection profiles (also reported by Hamilton in this volume) suggest the presence of a major zone of faults that offset Precambrian and Paleozoic rocks in northeastern Arkansas. The zone is coincident with the major trend of Mississippi embayment seismicity. Another zone of faults that offset Paleozoic and younger sediments delineate a graben-horst complex occurs beneath Ridgely Ridge in Tennessee. The largest fault has a vertical displacement of 80 m, most of which occurred post middle Eocene. Tabular intrusive masses are interpreted to underlie the centers of some of the grabens. The evidence indicates that the igneous rocks were intruded during several time periods, perhaps in a resurgent fashion.

3. Trend-surface and gridding analyses were made of two-way travel times from seismic reflection profiles in order to generate models of the buried Paleozoic bedrock surface between Ridgely, Tenn., and New Madrid, Mo. Results of the analyses show a distinct uplifted area that is generally coincident with the uplift expressed at the ground surface. The subsurface uplift can be divided into a 40 sq km, roughly equidimensional uplift located directly north of Tiptonville, Tenn., and an areally larger uplift that extends from the southern end of Reelfoot Lake south-southwestwardly to beyond Cottonwood Grove, Tenn. The trends of the two segments of the uplift are subparallel to zones of modern seismicity in the area. The surface expression of the uplift and the spatial relationship to the seismicity suggest that the stresses responsible for the uplift are active today.

4. Field analyses of sand dikes located along the banks of the St. Francis River in the Western Lowlands of southeastern Missouri indicate that the dikes formed by liquefaction that accompanied high-intensity earthquakes. The dikes range from 5 m to 25 m in length and from less than 1 cm to 20 cm in thickness. The identification of these features is significant because they enlarge considerably the area of surficial deformation known to have been caused by high-intensity earthquakes. Heretofore, no liquefaction structures had been identified west of Cramleys Ridge in the Mississippi Valley. Recognition of the sand-blow dikes may have an impact on ideas concerning the location of seismic source zones, reconstructed intensities of historic high-magnitude earthquakes, and ground motion, attenuation in the upper Mississippi embayment.

Several exploratory trenches were excavated in cooperation with S. Obermeier across sand blows located in the Obion River valley of northwestern Tennessee.

The blow sands are composed of medium-to-coarse-grained very pale brown quartzose sand. Cross-sections show that most of the sand blows consist of massive unstratified sand that rests on a relatively horizontal layer of overbank clays. One of the sand blows, believed to have formed before 1800, has a highly irregular structure, including intensely folded laminae, bowl-shaped structures, and contorted dike-like features.

Reports

Crone, A. J., and Russ, D. P., 1979, Preliminary report on an exploratory drill hole--New Madrid test well-1-X in southeast Missouri: U.S. Geological Survey Open-File Report 79-1216, 12 p.

Russ, D. P., 1979, Style and significance of surface deformation in the vicinity of New Madrid, Missouri: U.S. Geological Survey Professional Paper, in review.

Zoback, M. D., Hamilton, R. M., Crone, A. J., Russ, D. P., and Brockman, S. R., 1979, Major fault zone associated with the main New Madrid seismic trend shown by seismic-reflection profiling !abs.1: Seismological Society of America Earthquake Notes, Eastern Regional Meeting, in press.

Zoback, M. D., Hamilton, R. M. Crone, A. J., Russ, D. P., McKeown, F. A., and Brockman, S. R., 1979, Recurrent intraplate tectonism in the New Madrid seismic zone: in TRU, prepared for submission to Science.

Northeast Tectonics and Geophysics

9730-00364

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Investigations

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

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

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

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

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

Results

1. We have compiled the most complete file of gravity data available for the Northeast and adjacent offshore regions. All stations have been terrain corrected except for innermost zones. Bouguer gravity maps of most $1^o \times 2^o$ quadrangles for New England have been put on open file. Additional maps at appropriate scales are in the works.

2. Aeromagnetic data for the Anna, Ohio area have been digitized and placed on open file. Results of the recent qeromagnetic survey of the central Gulf of Maine are also out. Aeromag data from the Boston $1^o \times 2^o$ quadrangle have been digitized and edited and will soon be put on open file.

3. In cooperation with the Branch of Marine Geology at Woods Hole we have collected several hundred miles of gravity, magnetic and seismic data off Boston and Cape Ann in the Gulf of Maine. We hope that this data will help us to identify faults in the basement and to extrapolate mapped onshore geology into the offshore regions. The area off Cape Ann in the vicinity of the 1755 earthquake appears to contain the intersections of a number of faults separating possibly as many as four different tectonic terrains.

Reports

Bothner, W. A., and Simpson, R. W., 1979, Gravity map of the Hartford $1^o \times 2^o$ quadrangle, Connecticut, New York, New Jersey, and Massachusetts: U.S. Geological Survey Open-File Report 79-1083, scale 1:250,000.

Bothner, W. A., Simpson, R. W., and Kucks, R. P., 1979, Bouguer gravity map of the Lewiston $1^o \times 2^o$ quadrangle, Maine, New Hampshire and Vermont: U.S. Geological Survey Open File Report 79-873, scale 1:250,000.

______, 1979, Bouguer gravity map of the Portland $1^o \times 2^o$ quadrangle, Maine and New Hampshire: U.S. Geological Survey Open-File Report 79-872, scale 1:250,000.

______, 1979, Bouguer gravity map of the Sherbrooke $1^o \times 2^o$ quadrangle, Maine and New Hampshire: U.S. Geological Survey Open-File Report 79-874, scale 1:250,000.

______, 1979, Bouguer gravity map of the Providence $1^o \times 2^o$ quadrangle, Rhode Island, Massachusetts, Connecticut and New York: U.S. Geological Survey Open-File Report 79-1084, scale 1:250,000.

Harlan, J. B., Simpson, R. W., and Kane, M. F., 1979, Digitized aeromagnetic map of the Columbus-Dayton area, Ohio and Indiana: U.S. Geological Survey Open-File Report 79-928, scale 1:250,000.

Simpson, R. W., Bothner, W. A., Diment, W. H., and Urban, T. C., 1979, Bouguer gravity map of the New York $1^o \times 2^o$ quadrangle, New York, New Jersey and Connecticut: U.S. Geological Survey Open-File Report 79-1082, scale 1:250,000.

Simpson, R. W., Bothner, W. A., and Hodge, D. S., 1979, Bouguer gravity map of the Bath $1^o \times 2^o$ quadrangle, Maine: U.S. Geological Survey Open-File Report 79-956, scale 1:250,000.

______, 1979, Bouguer gravity map of the Presque Isle $1^o \times 2^o$ quadrangle and parts of adjacent quadrangles, Maine, New Brunswick, and Quebec: U.S. Geological Survey Open-File Report 79-1081, scale 1:250,000.

Simpson, R. W., Bothner, W. A., Kucks, R. P., 1979, Bouguer gravity map of the Albany $1^o \times 2^o$ quadrangle, New York, Connecticut, Massachusetts, New Hampshire, and Vermont: U.S. Geological Survey Open-File Report 79-970, scale 1:250,000.

______, 1979, Bouguer gravity map of the Glens Falls $1^o \times 2^o$ quadrangle, New York, Vermont, and New Hampshire: U.S. Geological Survey Open-File Report 79-957, scale 1:250,000.

______, 1979, Bouguer gravity map of the Lake Champlain $1^o \times 2^o$ quadrangle, New York, Vermont, and New Hampshire: U.S. Geological Survey Open-File Report 79-958, scale 1:250,000.

Simpson, R. W., Bothner, W. A., and Shride, A. F., 1979, Offshore extension of the Clinton-Newbury and Bloody Bluff fault system of northeastern Massachusetts: To appear in Symposium Volume, The Caledonides in the USA, Blacksburg, VA, September 1979.

U.S. Geological Survey, 1979, Aeromagnetic map of the central part of the Gulf of Maine: U.S. Geological Survey Open-File Report 79-1198, scale 1:250,000.

Norumbega Fault Zone, Maine

9510-02165

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Investigations

1. Petrographic observations of graniticrocks found within and along the Norumbega Fault Zone.

Results

1. Three large (>500 km^2) plutons (Lucerne, Lead Mountain, and Cranberry Lakes) lie south of and are truncated by the Norumbega Fault Zone. The Bottle Lake Complex lies north of the Fault Zone. Granitic rocks are found within the Fault Zone, including the distinctive Wabassus Lake granite. Petrographic variations between the plutons are distinctive. The granitic rocks within the Fault Zone correlate with the Lead Mountain and Cranberry Lakes plutons, but not with the Lucerne, Bottle Lake, or Wabassus Lake plutons.

The major fault motion must lie along the most northwesterly fault traces, as these separate the granites within the zone from those north of the zone. No plausible correlation between granites can be made across the fault zone. The total amount of offset along the Norumbega Fault Zone remains unknown.

The chemistry of the plutons across the zone is distinctive (Loiselle and Ayuso, 1979). This result implies that the crustal sources are distinctive on either side of the Fault Zone, and is suggestive of a significant crustal boundary.

The Vassalboro formation (Kellyland = Bucksport = Flume Ridge Formations) lies on both sides of the fault zone and is probably of Late Silurian to Early Devonian age. It is suggest that the Fault Zone represents the reactivation of an earlier zone that was active duriing the Early Paleozoic.

Reports

None.

Neotectonic Synthesis of U.S.

9540-02191

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Investigations

A formal request for proposals (RFP 665W) was issued in the spring of 1979 to solicit regional tectonic analyses in support of this project. Thirty one proposals amounting to more than $2,000,000 were received and evaluated, and 8 contracts amounting to about $200,000 have been awarded for the following work:

W. M. Johns Montana Bureau of Mines & Geology Butte, Montana	Neotectonic Analysis of a 2^{o} Strip Across S. Montana Extending from the Idaho to the North Dakota Line, map scale 1:250,000
E. J. Bell University of Nevada Reno, Nevada	Regional Neotectonic Analysis of the Northern Walker Lane, map scale 1:500,000
D. R. Currey University of Utah Salt Lake City, Utah	A Neotectonic Analysis of the Late Bonneville Region, map scale 1:500,000
S. I. Dutch University of Wisconsin Green Bay, Wisconsin	Cenozoic Neotectonics of the U.S. Portion of the Canadian Shield, map scale 1:1,000,000
R. D. Yeats Oregon State University Corvallis, Oregon	Regional Neotectonic Analysis of the Ventura Basin, Transverse Ranges, California, map scale 1,100,000
D. P. McCrumb Woodward-Clyde Consultants San Francisco, California	Regional Neotectonic Analysis of Willapa Hills Region, Southwestern Washington, map scale 1:250,000
K. L. Wilson and B. A. Schell Fugro, Incorporated Long Beach, California	A Regional Neotectonic Analysis of the Sonoran Desert, map scale 1,500,000
L. K. Lepley L. K. Lepley Associates Tucson, Arizona	Neotectonic Map of Arizona 1:1,000,000

Work is scheduled to be completed by fall, 1980, and products will be issued by the Geological Survey.

In order to examine the progress of deformation of the Atlantic coastal plain through time, a series of maps is being compiled at 1:1,000,000 for presentation at 1:2,500,000, showing 1) gross configuration of the basement surface (post-Newark unconformity) 2) base of late Cretaceous, 3) base of Tertiary, 4) base of Neogene, and 5) late Cenozoic shorelines. Because of uncertainties in the date (principally drillhole information), this has involved reconsideration of the literature sources, in cooperation with G. Gohn, T. Cronin, W. Dillon and others actively working on Coastal Plain and offshore stratigraphy. Features larger than about 100 km can be defined reasonably well: smaller features, although locally suggested by the data, must be considered uncertain until better control is available, with a few well documented exceptions.

The use of gross topography to help place limits on vertical deformation is being examined. Construction and interpretation of various kinds of topographic representatives (envelope maps, relief, average altitude) are being explored, in part in cooperation with M. Kane and W. Diment, who are working on average altitude maps of the U.S.

As part of this exploration of topography, a preliminary study of computer simulation of the evolution of erosional topography has been made. An algorithm to distribute an average erosion rate over a terrain in terms of altitude and slope was written by Larry Mayer, based on the idealization that erosion tends to produce topographic profiles involving the least work to transport material. Rates of erosion and uplift can be varied, and the computer program produces descriptions of both the three dimensional form of the topography and its hypsometry, slope, relief, and altitude distribution through time. The depositional regime is ignored, and detritus is assumed to vanish from the system above some stated base level. The program has been applied to examples of a basin-range fault block and a retreating plateau rim. Results are reasonable, and suggest, for example, that the rate of pedimentation varies with initial relief and steepness of mountain fronts and with rate of erosion.

Negotiations were successful in recruiting additional work in cooperation with this project under the Survey project Quaternary Dating and Neotectonics. Mike Machette will prepare a map of Quaternary faulting and stratigraphic control along the Rio Grande Rift in New Mexico, and Steve Colman will make a neotectonic analysis of the State of Colorado and adjacent Paradox Basin area. Map scales will probably be 1:500,000 for both.

Seismogenic Zones of the United States

9950-01849

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Investigations

Work under this project is closely coupled with the Neotectonics project of C. M. Wentworth.

1. Continued compilation and analyses of geologic, geophysical, and seismological data of southeastern United States.

2. Continued refining of a computer program to calculate models of the evolution of erosional topography.

3. Initiated plan to prepare draft seismogenic zone maps of various regions of the United States needed to make probabilistic ground motion maps.

Results

The first workshop of a series to be held about every 6 weeks to prepare draft seismogenic zone maps was held in Golden on October 10-11, 1979. A group of 13 scientists from the Academic, Industry, and Survey communities discussed and evaluated the available information relevant to seismogenically zoning the Great Basin. The products of the workshop are a draft seismogenic zone map and a brief report summarizing the discussions and information. The report is being prepared by R. C. Bucknam.

Characteristics of Active Faults in the Great Basin

9950-01538

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Investigations

Profiles were measured across wave-cut scarps developed at the high stand of Lake Bonneville at 4 widely spaced localities in western Utah. Data derived from the profiles were compared with similar data from fault scarps.

Results

Profiles across the wave-cut scarps were treated in the same manner as the fault scarp profiles described by Bucknam and Anderson (1979). Data from the shoreline profiles (figure 1) define a line ($\theta = 3.84 + 21.0 \log H$) nearly parallel to those from similar data from fault scarps. Although the shoreline scarps transect a variety of alluvial fan environments from apex to toe, the standard deviation of observations about the regression line is only 1.6°. This suggests that whatever variations in grain-size and sorting may exist in unconsolidated alluvial fan deposits, they have no apparent effect on the scarp slope angle/log scarp height relationship.

The 12,000 to 15,000 year B.P. age limits for the high stand of Lake Bonneville and the well-determined shoreline data should provide a useful calibration for estimating ages of fault scarps in the Great Basin.

Reports

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

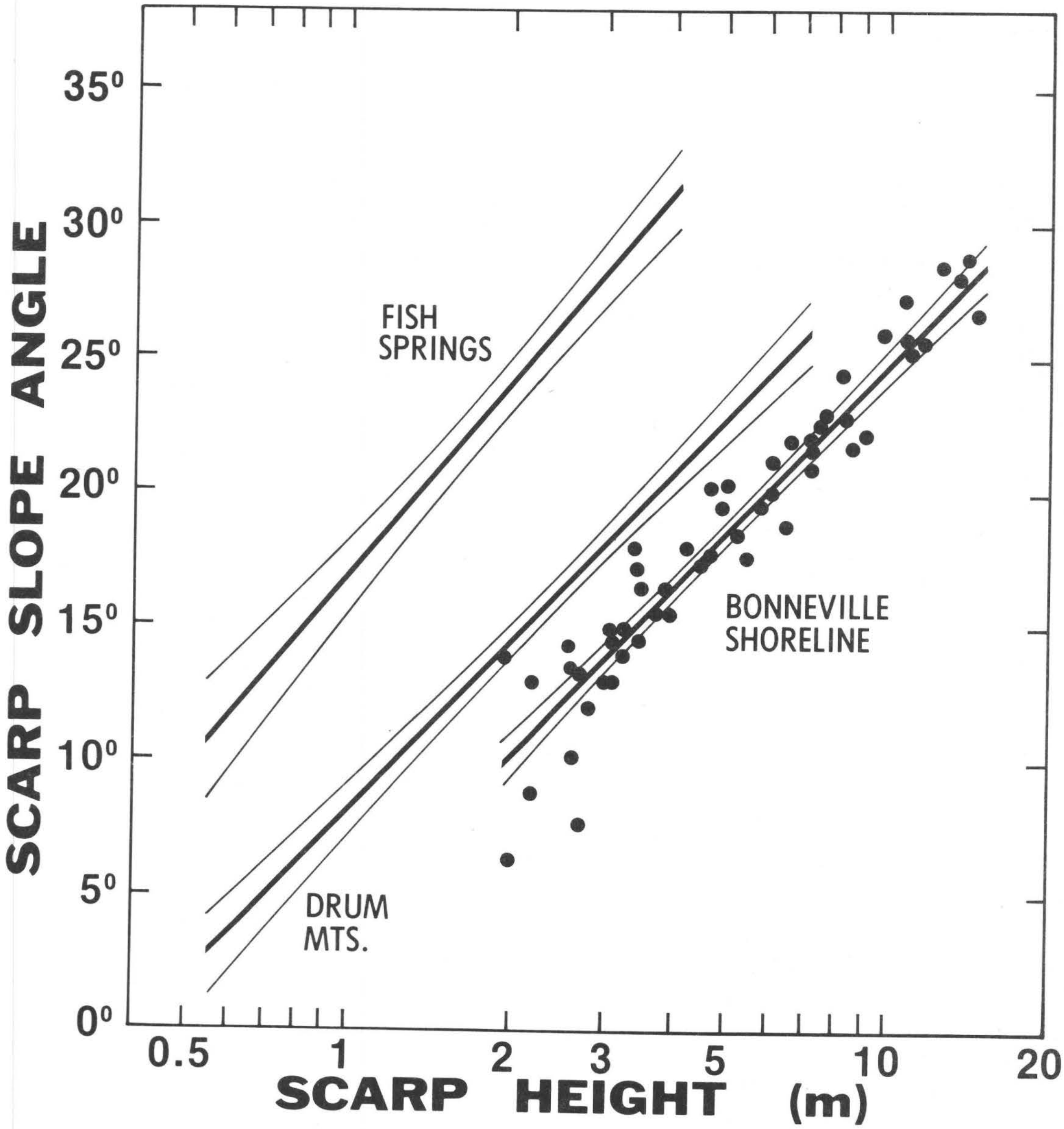

Figure 1.-Regression line to measurements (dots) of the wave-cut scarp developed at the high stand of Lake Bonneville. Regression lines to measurements of fault scarps at Fish Springs and Drum Mountains reported in Bucknam and Anderson (1979) shown for comparison. Curved lines on either side of regression lines are the 95% confidence intervals.

Soil Morphology and Fault Movement

14-08-0001-G-520

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Investigations

The effect of faulting on reorientation of soil pores was studied. Field sampling sites included: the Black Rock fault, near Gerlach, Nevada; the San Andreas fault at Cuddy Valley, California; and the La Jencia fault near Magdalena, New Mexico. Results were tabulated as "rose diagrams," where direction within the diagram represents the orientation and length within the rose diagram represents the sum of the length of pores oriented in that direction.

Results

1. It was anticipated that the orientation of small size pores would be different than the orientation of large pores. Data sets, representing the data collected from a single soil sample, were subdivided into five subsets according to pore size, with the same number of pores in each subset. A study was carried out to determine the minimum number of pores that must be observed in order to obtain reproducible rose diagrams. It was found that reproducible rose diagrams summing all sizes of pores were obtained when 600 pores were measured. When data were divided into 5 pore size classes, with the same number of pores in each subclass, 600 observations (120 pores in each subclass) were adequate for reproducible rose diagrams characterizing the smallest pores. However, 900 observations (180 pores in each subclass) were needed to obtain reproducible rose diagrams for the largest size pores; that is, as the length of pores increases more pores must be measured in order to obtain reproducible results.

2. Soil samples were collected immediately adjacent to the zone of movement and at regular distances away from the fault. Reorientation of soil pores was observed immediately adjacent to the zone of movement. No reorientation was observed at distances greater than 0.3 feet from the zone of movement.

3. Kubiena boxes are usually used to collect undisturbed soil samples for micromorphological investigations. It was found that it was virtually impossible to collect undisturbed samples from within the zone of maximum disturbance using these boxes. An alternative sampling method has been developed and field tested in dune sands.

4. Figure 1 shows rose diagrams displaying the orientation of soil pores from soils associated with the La Jencia fault. M. Machette (U. S. Geological Survey, Denver, Colorado) has estimated that the last movement of

this fault occurred during Late Pleistocene time. Samples were collected from the Pleistocene soil (A and B), within the zone disrupted by movement of the fault (E), and from a soil block that might be an overturned block (F) of soil that fell off the scarp face after movement of the fault. Three data classes are shown: rose diagrams summing all pores, summing the longest pores, and summing the smallest pores, when the pores had been subdivided into five subclasses according to pore size.

Rose diagrams from the zone of movement (Sample E) show pore orientation patterns different from that of the soil (samples A and B) or the overturned block (F). The large size pores from the zone of movement showed the highest degree of orientation of all pores from this site.

The long axis of rose diagrams from the rotated block (F) and long axis of rose diagrams from the undisturbed soil (A and B) show a 20 to 50 degree difference between the major pore orientation directions.

Reports

Low, Alison J., Lowell A. Douglas and David W. Platt. 1979. Soil Component Orientation in Faulted Soils. Agron. Abstracts. p. 193.

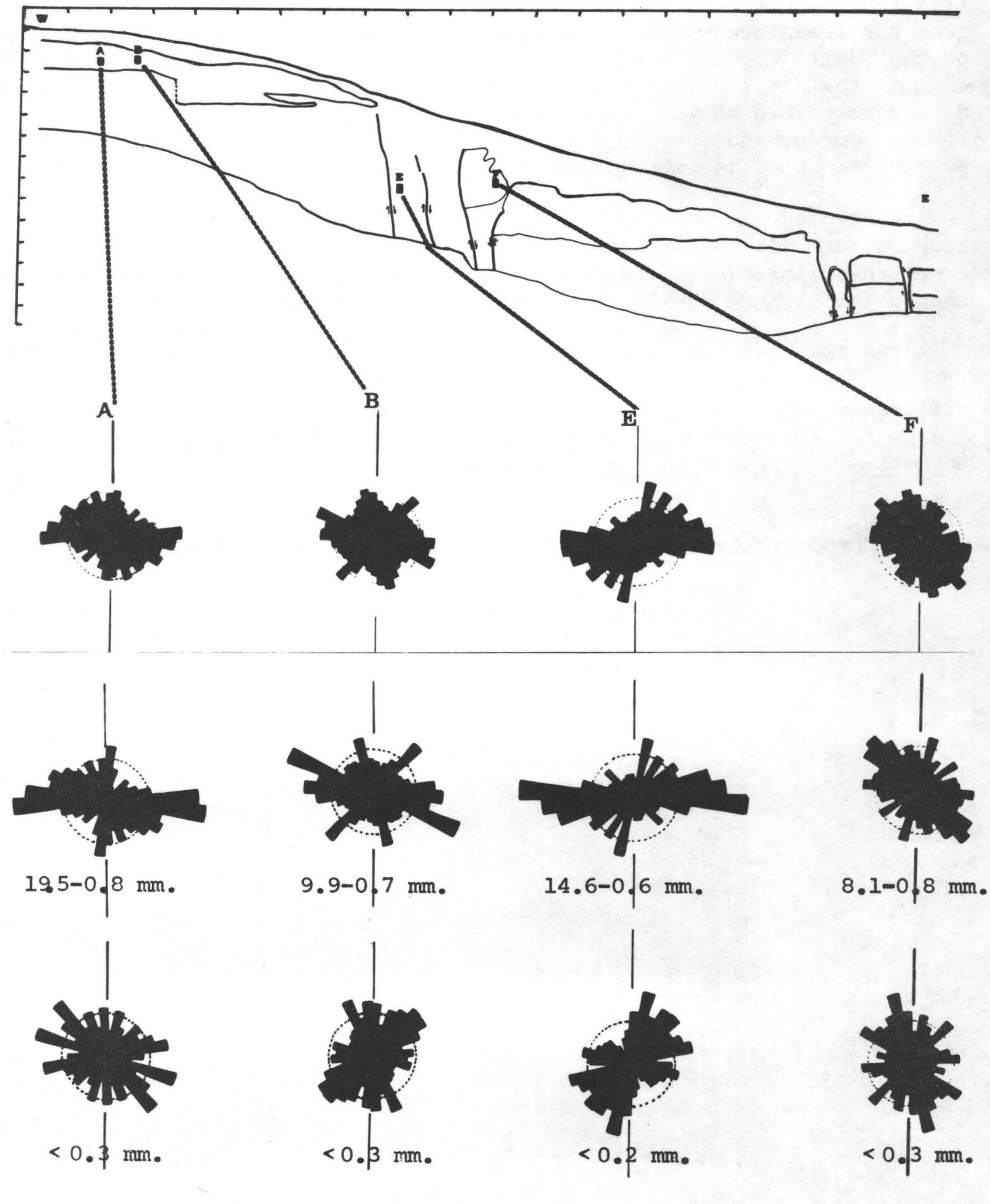

Figure 1. Rose diagrams showing length and orientation of pores in the soil associated with the La Jencia fault. Scale "ticks" are 1 meter apart. Top rose diagrams include all pores; the sizes of the pores included on the other diagrams are shown above.

Neotectonics in Meade County, Kansas

9530-02169

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Investigations

Detailed stratigraphic, paleontologic, tephrochronologic, isotopic (age) studies combined with geologic mapping along the trace of the Crooked Creek fault in Meade County, Kansas.

Results

Studies along the trace of the northeast-trending Crooked Creek fault zone (Pleistocene) in Meade County, Kansas, reveals a complex history of fault movement and related deposition of sediments in late Cenozoic time. An early period of north-northeast-trending faulting (ease side down; 50 m throw) of pre-Ogallala Formation age (late Miocene) is shown by study of deep geophysical logs of Paleozoic rocks in oil and gas wells. Following deposition of the Ogallala Formation (late Miocene; 10-5 m.y.), recurrent movements along the Crooked Creek fault zone resulted in about 30 m of throw west side down. Sandstone and claystone of the Rexroad Formation (Pliocene; 4.5-2.5 m.y.), which are well dated by many fossil vertebrates, were deposited west of the fault zone. Recurrent movements along the Crooked Creek fault zone deformed the Rexroad sediments about 2.2 to 2.5 million years ago. A thin sheet of clean washed sandy gravels and associated overbank silts of the Stump Arroyo of the Crooked Creek Formation of earliest Pleistocene age were laid down by the ancestral Arkansas River over wide areas in Meade County about 2.1 million years ago. Renewed movements along the fault zone offset the Stump Arroyo (east side down; about 20 m throw) and the lower part of the Crooked Creek Formation containing the type B Pearlette ash and the Borchers fauna (2.0 m.y.). Following the deposition of the upper part of the Crooked Creek Formation (Pleistocene; 1.4-0.6 m.y.), which contains many vertebrate fossils and the Cerro Toledo(?) and the Type O Pearlette ash beds, the latest movements along the Crooked Creek fault occurred.

Correlating and Dating Quaternary Sediments by Amino Acids

9460-01996

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Investigations

1. Having previously established the analytical variability that can be expected in applications of the amino acid dating technique, and having made interlaboratory comparisons of amino acid measurements to assure comparability of results among laboratories, we have now begun investigating other chemical measurements to supplement amino acid racemization data and thus increase confidence in ages estimated by means of amino acid D/L ratios.

2. Having previously established by amino acid dating a geologically reasonable time framework for Pleistocene shell deposits at Willapa Bay, Washington, we have now applied the technique to dating a shell deposit on Whidbey Island, Washington.

Results

1. We have examined the concentrations of amino acids and their corresponding D/L ratios in the bivalve mollusk *Saxidomus* to determine if any consistent relationships exist that would aid in age estimations. Shells from eleven Pacific coast localities were studied. Regression lines relating amino acid concentrations and D/L ratios for phenylalanine, leucine, valine, glutamic acid, and proline have similar slopes suggesting these amino acids are following similar reaction pathways. Alanine and aspartic acid follow different pathways. The chemical basis for these relationships is not yet known. These regression lines can serve as guides to the amount of amino acids that can be expected for a given D/L ratio. By means of these relationships it may be possible to distinguish leaching and contamination processes and thus be useful in deciding which samples are more reliable for age estimations by the amino acid techniques. We have also compared the natural logarithms of the ratio of concentrations of glycine to alanine versus D/L ratios of alanine for *Saxidomus* from the same localities. The regression through the data points has a correlation coefficient of 0.97 indicating excellent correlation between the two parameters and suggesting that the glycine/alanine ratio can be useful in age estimations.

2. A shell deposit exposed at Admiralty Bay on Whidbey Island, Washington, has been dated by radiocarbon at 36,200 $^{+2600}_{-1900}$ yr. BP. Amino acid D/L ratios as well as concentrations and concentration ratios of amino acids in *Saxidomus* indicate that this locality is actually older. We have estimated an amino

acid age for this locality using techniques previously applied at Willapa Bay. The approach is to (1) assume that first order kinetics apply; (2) use these kinetics to calibrate rate constants for Saxidomus at the calibration locality at Hope Island (30 km north of Whidbey Island locality) where shells have been radiocarbon dated at 12,400 yr; (3) adjust these rate constants by means of the Arrhenius equation and inferred diagenetic temperatures; and (4) calculate the age from the adjusted rate constants and measured D/L leucine values. Our results indicate that the Whidbey Island locality is about 80,000 yr old rather than 36,000 yr old as indicated by radiocarbon. The radiocarbon age, however, was measured on some shell carbonate and is likely a minimum age. Stratigraphic relationships suggest that this locality lies between the interglacial Whidbey Formation (Sangamon?) and middle Wisconsin age sediments. The amino acid age is consistent with the stratigraphy and geologic history of the area.

Reports

Kvenvolden, K.A., Blunt, D.J., and Clifton, H.E., 1979, Amino acid racemization in Quaternary shell deposits at Willapa Bay, Washington: Geochim. Cosmochim. Acta, v. 43, p. 1505-1520.

Kvenvolden, K.A. and Blunt, D.J., 1979, Amino acid dating of bone nuclei in manganese nodules from the North Pacific Ocean: in Bischoff, J.L. and Piper, D.Z., Marine Geology and Oceanography of the Pacific Manganese Nodule Province, Plenum Publ. Corp., p. 763-773.

Bada, J.L., Hoopes, E., Darling, D., Dungworth, G., Kessels, H.J., Kvenvolden, K.A. and Blunt, D.J., 1979, Amino acid racemization dating of fossil bones, I: Interlaboratory comparison of racemization measurements: Earth and Planetary Science Letters, v. 43, p. 265-268.

Kvenvolden, K.A. and Blunt, D.J., 1979, Amino acid dating of Saxidomus giganteus at Willapa Bay, Washington, by racemization of glutamic acid: in Hare, P.E. and King, K.L., The Biogeochemistry of Amino Acids, John Wiley and Sons, New York (in press).

Kvenvolden, K.A., 1979, Interlaboratory comparison of amino acid racemization in a Pleistocene mollusk, Saxidomus giganteus: in Hare, P.E. and King, K.L., The Biogeochemistry of Amino Acids, John Wiley and Sons, New York (in press).

Kvenvolden, K.A., Blunt, D.J. and Robinson, S.W., 1979, Amino acid dating of an archaeological site on Amaknak Island, Alaska, Geological Society of America, Abstracts with Programs, v. 11, p. 462.

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

14-08-0001-17721

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Investigations

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

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

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

Results

1. For the entire Atlantic Coastal Plain, the paleomagnetic data place the Brunhes/Matuyama polarity boundary (about 0.72 myBP) in the interval between the deposition of the upper Pleistocene Canepatch (Normal [N] polarity) and the lower Pleistocene Waccamaw (Reversed [R] polarity) Formations in the Cape Fear Arch region, and between the upper Pleistocene Flanner Beach (N) and lower Pleistocene Croatan (R?) Formations in their type area on the Neuse River, North Carolina. This marker horizon is important for interpreting Quaternary tectonism in the Coastal Plain, as well as dating sea-level fluctuations and allowing correlation of the onshore biostratigraphic record with the deep-sea record and a global time scale.

2. In the Charleston, South Carolina, area, paleomagnetic samples from outcrops and fully-oriented, split-spoon or Shelby tube cores drilled by the USGS, identify Waccamaw-age deposits (reversed polarity) that formed in a fluvial to marine deltaic environment. Additionally, preliminary paleomagnetic data from an upper Pliocene calcarenite exposed along Goose Creek in North Charleston, South Carolina, is time-equivalent to the so-called Bear Bluff Formation near the North Carolina-South Carolina State line and has normal polarity (Gauss Normal Epoch [?]: 3.41-2.47 myBP). Younger, post-Waccamaw Pleistocene sediments have normal polarity and were deposited during the Brunhes Epoch (0.72 my to present). This threefold division of the Pliocene and Pleistocene sedimentary record can now be made independently of geomorphic and topographic evidence, and the magnetostratigraphy, in conjunction with litho- and biostratigraphic data,

can be used in the Charleston area to test conflicting morphostratigraphic correlations made by previous workers. Another important application is more precise dating of surficial stratigraphic units in the area most directly affected by the 1886 Charleston earthquake.

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

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

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

Reports

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

Soil Correlation and Dating, Western Region

9540-02192

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Investigations

1. About sixty-five soil profiles (~200 samples) have been described, sampled, and submitted for laboratory analysis to study changes of properties in well documented time sequences (chronosequences) of soils in the western United States. Partial or complete laboratory data is now available for all of these profiles. Profiles sampled include soils formed on arkosic alluvium of the Merced River and volcanic-metamorphic source alluvium along Dry Creek in the northeastern San Joaquin Valley, California; soils formed on colluvium from metavolcanic and volcanic rocks in the western Sierra Nevada foothills; soils formed on alluvium from volcanic sources along the Cowlitz River west of Mt. Rainier, Washington; and soils on Neoglacial and latest Wisconsin moraines derived from granitic rocks in the Front Range of Colorado. We also have access to data for chronosequences of soils in New Mexico (arkosic and mixed sources) and central Pennsylvania (mixed sedimentary sources). The areas listed above encompass a wide range of climates and vegetation. Data analysis and interpretation are being carried out cooperatively with Michael J. Singer, Alan Busacca, and Richard Meixner (University of California, Davis); F. C. Ugolini and John Bethel (University of Washington); and Peter W. Birkeland (university of Colorado).

2. R. M. Burke, J. W. Harden, and D. E. Marchand have assessed 12 potential soil chronosequences in southern California, Arizona, Colorado, Wyoming, Idaho, and West Texas. We will sample two coastal chronosequences, one in the Ventura area and one in Santa Cruz County this winter and spring. We will also cooperate with Les McFadden, Bill Bull, and John Tinsley in the sampling, analysis, and interpretation of soils in the Mojave Desert and Southern California.

3. We continue to coordinate our work with other projects involved in Quaternary dating, especially uranium-trend dating (J. N. Rosholt), amino acid dating (K. R. Lajoie, John Wehmiller, Keith Kvenvolden, and Etta Peterson), tephrochronology (A. M. Sarna-Wojcicki), magnetostratigraphy (Ken Verosub, University of California, Davis), thermoluminescence (Rodd May), and other studies involving soils (Pierce, Shroba, Machette).

4. A terminal-operated program, MINITAB, is being used for storage, plotting, and statistical interpretation of soil information. Soil data stored for each profile and sample include 25 field properties; soil thin section information; quantitative mineralogy of very fine-sand fractions; semiquantitative mineralogy of clay fractions; bulk density; complete particle size information; 25 chemical properties of the less-than 2 mm soil fraction; and bulk chemistry of the less-than 2 mm and silt-plus-clay fractions (13 elements by X-ray spectroscopy, 26 elements by neutron activation).

Results

1. Time plots of nearly all properties studied show clear but nonlinear changes with time. Many properties show rapid increases up to 10,000 to 100,000 years, followed by a slower rate of increase. Rates of change are controlled by both climate and parent material: soil properties change more rapidly in western Washington than in the drier San Joaquin Valley; rates are more rapid for volcanics than for granitic parent materials and more rapid for fine-grained than coarse-grained deposits.

2. Results from x-ray fluorescence analyses of 44 soil samples from the Merced, Tuolumne, and Stanislaus River areas of the northeastern San Joaquin Valley indicate striking and systematic changes in bulk soil chemistry with age. Aluminum, silicon, iron, calcium, and magnesium show the best trends, but manganese, sodium, potassium, nickel, and zirconium also yield good plots against absolute time. Calcium, magnesium, strontium, and sodium are quite strongly intercorrelated, whereas titanium varies independently of all other elements and shows no trend with soil age. Titanium therefore appears to be a useful index element. The progressive depletion in zirconium with age indicates that this element may be less stable than has been commonly assumed.

3. Morphological properties observable in the field are usually a reliable index of soil age. We have found the following properties to be most useful: 1) presence, nature, and thickness of B horizons or horizons in the B position, 2) depth to unweathered parent material, 3) B horizon structure, 4) location, thickness, and abundance of oriented clay films in B horizons, 5) B horizon texture and consistency relative to A and fresh C horizons, 6) nature, abundance, and size of interstitial and tubular pores in B horizons, 7) color of B horizon relative to A and C horizons, and 8) number and distinctness of soil horizons. In old desert soils where B horizons have been eroded, the character of subsoil horizons of calcium carbonate accumulation becomes more diagnostic of soil age than the overlying B horizons.

4. Thin sections of soil B horizons reveal progressive textural development. Stages of development can be recognized for correlation purposes. Thin sections and grain counts of A horizons show progressive etching, alteration, and depletion of weatherable minerals with time.

5. Particle size analyses provide valuable information for correlation and dating. Content of less-than-2 and less-than-1 micron clay constitute two of the most reliable age indices for soils in all chronosequences studied. Silt and sand fraction data permit categorization of parent materials and adjustment of clay contents for profile stratification or textural differences between profiles.

6. Bulk density analyses show very small standard deviations between replicate samples. Bulk density increases rapidly during the first 10,000 to 20,000 years of soil development, then increases at a slower but steady rate to a limiting value of about 2.0 g/cc. The product of bulk density and clay content, summed through a soil profile above fresh parent material correlates very well with soil age.

7. Semiquantitative clay mineralogy appears to be a promising technique, although our present data are limited. Arkosic chronosequences tend to show progressive depletion of illite and concomitant increase in kaolinite/halloysite, whereas volcanic and metavolcanic parent materials show a gradual build-up in smectite with time.

8. Soil properties related to leaching (pH, extractable cations, base saturation) become more useful as age indices in regions where precipitation is moderate to high. pH decreases and total profile hydrogen ion content increases with age in the Merced, Dry Creek and Cowlitz chronosequences. In the Sierra Nevada foothills, however, older soils are invariably buried beneath younger deposits and the pH and extractable cations change rapidly following burial.

9. Cation exchange capacity increases with clay content and therefore with the age of a soil. Because CEC is also affected by organic matter and clay mineral composition of the soil, it tends to be less useful as an age index than other soil properties. Determination of CEC and extractable cations, however, permit calculation of base saturation percentage, which may be a useful parameter for soils in humid regions.

10. Well drained and oxidized soil profiles display increases in dithionite-extractable free iron (Fe_d) and aluminum (Al_d) oxides with time. Free iron appears to be lost in soils subject to reduction during their development. The rate of Fe_d and Al_d increase is clearly dependent upon climatic and vegetational environment.

11. Organic carbon values, like bulk density determinations, are readily reproducible. Organic carbon shows a smooth exponential decrease with depth, but the rate of decrease is greater in older soils. It may be possible to determine approximate soil age back to about 100,000 years, independent of parent material, from organic carbon profiles. Carbon is also a valuable aid in recognition of buried soils.

12. In general, profile summations (e.g., total clay in profiles), horizon ratios (e.g., free iron in B/free iron in A), and differentials (B-A, B-Cn) tend to correlate better with time than do absolute values of individual variables.

13. Under ideal circumstances (a soil adhering closely to a well studied chronosequence), a careful profile description and full laboratory analysis will permit accurate age estimation of relict soils within about 25 percent of the stated value. Further work will attempt to reduce this margin of uncertainty. Extreme care in soil profile site location, description, and sampling are essential to obtain reliable and reproducible results.

Reports

Burke, R. M., and Birkeland, P. W., 1979, Reevaluation of multiparameter relative dating techniques and their application to the glacial sequence along the eastern escarpment of the Sierra Nevada, California: Quaternary Research, v. 11, no. 1, p. 21-51.

Busacca, A. J., Meixner, R., and Singer, M. J., 1979, Rates and processes of clay mineral transformation in a soil chronosequence from the Merced River, California (abs.): Agronomy Abstracts and Programs for 71st Soil Science Society of America Annual Meeting, Fort Collins, Colorado, p. 188.

Harden, J. W., and Marchand, D. E., 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 American Society of Agronomy at Davis, California.

Marchand, D. E., and Harden, J. W., 1979, A stratigraphic sequence of Quaternary colluvial and alluvial deposits and soils, western Sierra Nevada foothills, California (abstract): Geological Society of America, Cordilleran Section, Abstracts with Programs, v. 11, no. 3, p. 90.

Marchand, D. E., Harden, J. W., Burke, R. M., Singer, M. J., Busacca, A. J., Meixner, R. E., and Bethel, John, 1979, Soils as a dating technique: Preliminary results from five chronosequences in the western United States (abs.): Geological Society of America, Abstracts with Programs, 1979 Annual Meeting, San Diego, California.

Meixner, R., Busacca, A. J., and Singer, M. J., 1979, Phosphorus fractions as age indicators in a chronosequence of alluvial soils (abs.): Agronomy Abstracts and Programs for Soil Science Society of America Annual Meeting, Fort Collins, Colorado, p. 229.

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

14-08-0001-17729

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INTRODUCTION

Our purpose is to determine the practicality of discerning Holocene movement along the Ramapo Fault Zone by comparing marine transgression curves based on data secured from tidal marshes along the Hudson Estuary which crosses the fault zone. Assuming the Ramapo Fault Zone has suffered movement during the Holocene Epoch (a presumption presently unsupported by the available data), we seek to ascertain the magnitude and frequency of the throw component of dip-slip movement by studying divergence in sea-level curves secured from tidal marshes both north and south of as well as within the fault zone. Our data are radiocarbon-dated basal peats which were also examined for their diatom content in order to determine whether the basal peats were actually generated in either brackish or marine waters.

ASSUMPTIONS

Our study is based on two basic premises both of which are verifiable. The initial assumption is that the surfaces of the tidal marshes from whose base we secure our basal peats are more or less in equilibrium with Mean High Water (MHW) which serves as our datum. Review of the literature and our own observations of the tidal cycle at these sites indicates our first assumption is valid and that the surfaces of our tidal marshes are within 0.25 meters of MHW.

Our second assumption requires that the first peats to accumulate on stable substrates (that is, bedrock, sand, glacial till or consolidated glacial drift) were indeed generated at the edge of encroaching sea level. Much existing literature defends this assumption and the marine and brackish diatom content of these basal peats appears to confirm this later premise. Finally, the general concordance of our data when plotted as elevation-time curves strongly suggests that we are working with a relatively consistent phenomenon.

SAMPLING METHODS

Our earlier sampling efforts secured 30 centimeter (cm.) long basal peat samples using a 2.54 inside diameter (I.D.) sampler. Two of these samplers whose design was based on the commonly available Davis Peat and Marl Sampler (which has an I.D. of 1.27 cm.) were fabricated in the Queens College Physics Department Machine Shop. Two major disabilities of the Davis-type sampler are its inability to penetrate sand and the limited volume of sample it can retain each trip down the bore. This necessitates repeated trips down to the sampling level in order to secure sufficient volume for radiocarbon dating. On the other hand, we have been able to obtain samples to a depth of 17 meters with the Davis-type sampler. Sixty basal peat samples were secured during our earlier efforts with this sampler.

More recently, we have been using the "Dutch" Gouge Auger Sampler manufactured by EIJELKAMP of Lathum in the Netherlands. Our gouge augers, driven by as many as four people, secures meter-long samples which have diameters of 3.0, 4.5 or 6.0 cm. The gouge auger has so far penetrated to a depth of 12 meters and also can secure a meter or more of sand - a distinct improvement of the Davis-type sampler.

SAMPLING STATIONS

We have probed 14 tidal marshes and secured basal peats from 13 of these stations. Four of these locations are north of the Ramapo Fault Zone (see Figure 1), two are within the fault zone and the remaining eight are south of the fault zone. We have been unable to find basal peat at the Con Hook tidal marsh and found little basal peat at Manitou, a surprise considering Cameron's (1970) report of the presence of considerable peat at this locality. The three New York City sites yielded only one sample each. Two or more basal peat dates have been obtained from the other nine stations.

RESULTS

Sixty radiocarbon-dated basal peats have now been secured and are plotted on Figure 2. An additional 63 samples are currently being dated in our Radiocarbon Laboratory. The data appear to document a regional tilting down towards the south as well as the suggestion that the Ramapo Fault Zone seems to have subsided in a graben-like manner during Holocene times. However, we anxiously await our new suite of dates for confirmation of these hypotheses. We will complete our current boring program after reviewing the dates obtained on the 63 samples now being processed in our laboratory.

REFERENCES CITED

Cameron, C.C., 1970, Peat Deposits of Southeastern New York: U.S. Geological Survey Bulletin 1317-B, p. B1-B32.

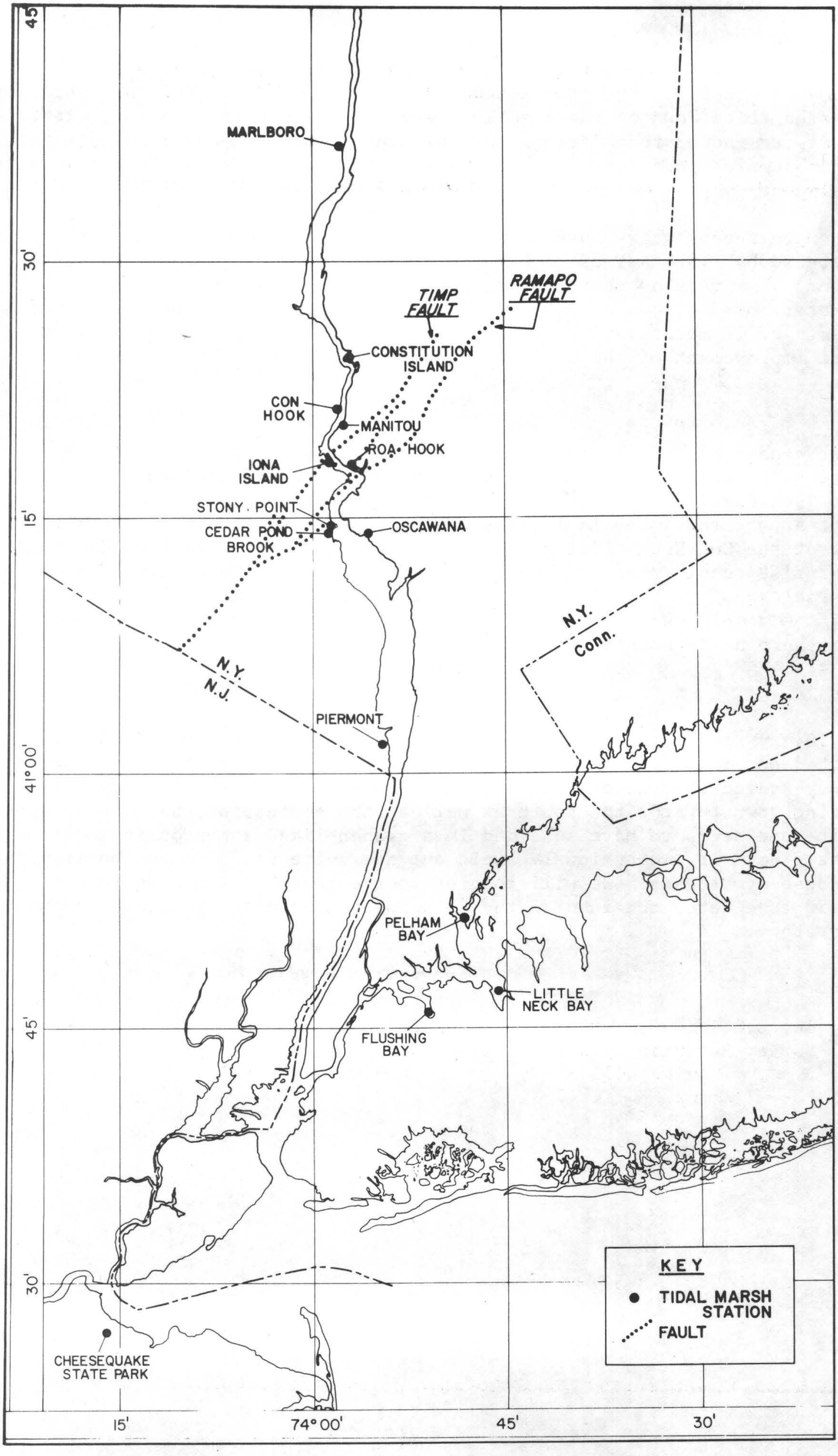

FIGURE 1. - Location Map of Ramapo Fault Zone and those tidal marshes yielding data for this project.

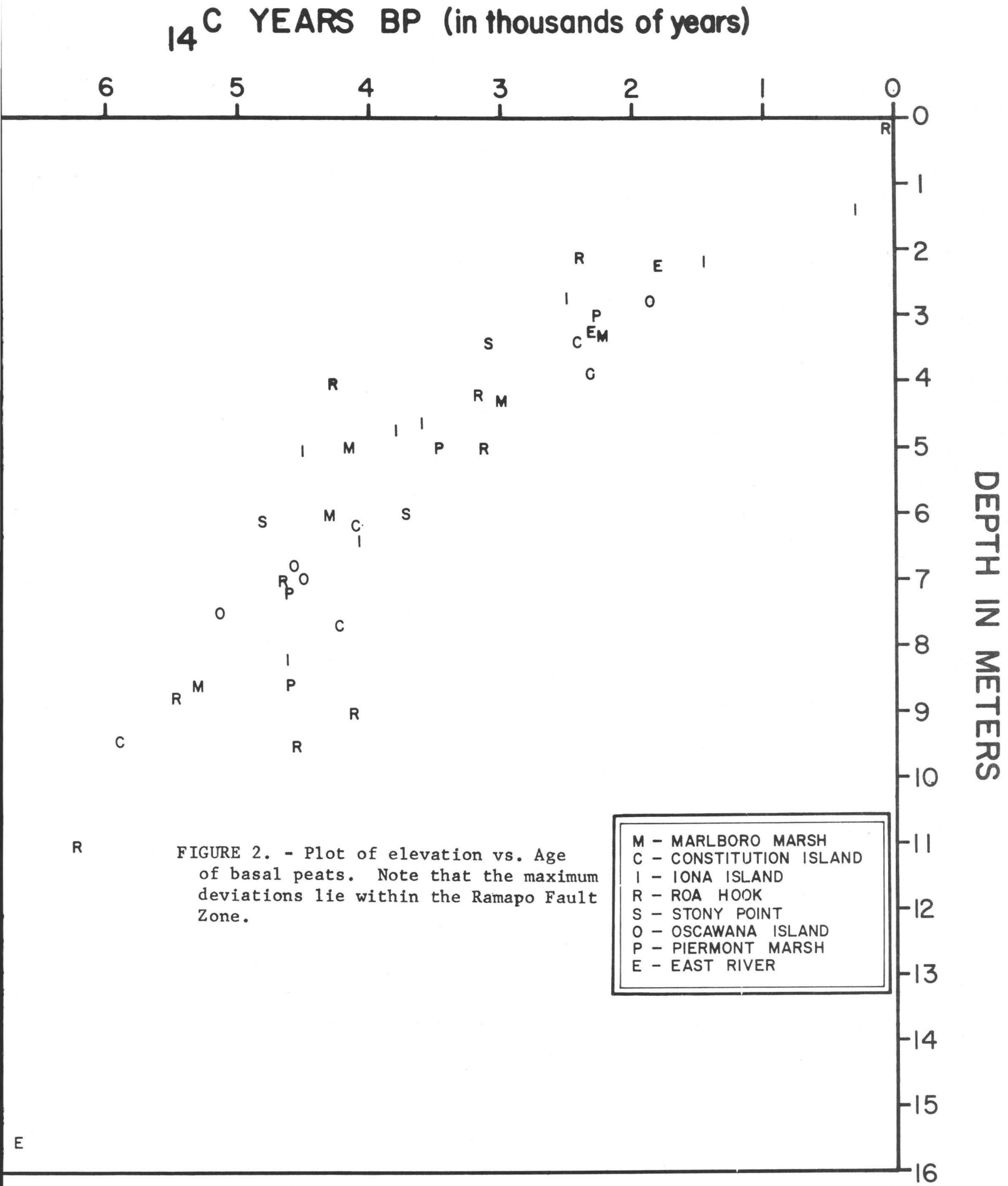

FIGURE 2. - Plot of elevation vs. Age of basal peats. Note that the maximum deviations lie within the Ramapo Fault Zone.

Quaternary Dating Techniques

9530-01559

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Investigations

1. Collaborated with John Rosholt to determine additional U-Th isochron ages for stratified caliche rinds from faulted alluvial fan gravels near Arco, Idaho.

2. Measured profiles of fault scarps and fluvial scarps near Arco, Idaho.

3. Gathered weathering data and pollen samples to help determine whether the Salmon Springs Glaciation along the Chehalis River, Washington, is of early Wisconsin or pre-Wisconsin age.

4. Described and sampled sections containing surface and buried soils, volcanic ashes, and basalt flows that provide framework for the loess stratigraphy of SE Idaho.

5. Initiated study of key buried and surface soils formed in lacustrine and subaerial sediments associated with Lake Bonneville in the vicinity of Salt Lake City, Utah.

6. Completed manuscript of a review report, "Decreasing rates of rock weathering and their mathematical analogs."

7. Completed data collection and analysis on the mineralogy and chemistry of weathering rinds on basalt and andesite; wrote first draft of a manuscript on this subject.

8. Mapped the surficial geology of the Crested Butte 7 1/2' quadrangle and investigated the possibility of applying various relative Quaternary dating techniques to the sequence of surficial deposits in the quadrangle.

Results

1. U-Th isochron ages of layers from stratified caliche rinds on clasts in faulted fan gravels near Arco, Idaho, yield stratigraphically and geologically reasonable results, with only 1 out of 8 age determinations clearly spurious. Based on the ages of multiple layers from three different caliche rinds, ranging from 35,000 to 160,000 years, the average rate of caliche rind deposition on carbonate clasts is 0.6 mm/10,000 years. The accuracy of this rate as a local dating technique is estimated to be about 30 percent or better.

2. Near Arco, Idaho, deposits about 160,000 years old, as dated by U-Th isochron analysis of caliche rinds, are offset a total of 18 m by multiple fault episodes. Fault offset is about 3 m on the youngest fans, dated as about 35,000 years old. On a Buchnam-Anderson type plot of log scarp height versus maximum scarp angle, the scarp cutting the youngest deposits falls on the same line as the scarps representing multiple offsets cutting the older deposits. This indicates that where the last fault offset occurred $>10^4$ years ago, the last of a sequence of offsets tends to dominate the morphology of the scarps on Buchnam-Anderson type plots.

3. An important time datum in the Puget Lowland area is the next-to-last glaciation, generally called the Salmon Springs Glaciation and traditionally considered to be of early Wisconsin age. Weathering rind data from end moraines and outwash along the Chehalis River suggest a pre-Wisconsin age is equally or more plausible. Pollen spectra from deposits discovered overlying the "lower Salmon Springs outwash" of Carson along the Chehalis River near Aberdeen have characteristics of the early phase of an interglacial (L. Heuser, oral commun., 1979), and indicate that the outwash probably correlates with an extensive glaciation dated elsewhere as about 140,000 years old.

4. Investigations of buried soils within the Lake Bonneville sequence near Salt Lake City, Utah, have been started in conjunction with W. E. Scott's stratigraphic study of earthquake hazards along the Wasatch Front. The new data indicate that soils with similar stratigraphic relations differ from site to site and lack diagnostic morphological features that permit consistent recognition at widely separated sections. This limits their usefulness as soil stratigraphic units. Despite similar parent materials, the Promontory Soil displays a wide range in thickness and degree of development. Moreover the type Promontory Soil tends to be better developed than equivalent soils at other localities; these soils are difficult to distinguish from the type Dimple Dell Soil. At some localities the Promontory Soil is multistory and consists of two or three soil profiles. Much of the lateral variability of the Promontory Soil can be attributed to environmental factors as well as to local differences in the amount of erosion and deposition. The Graniteville and Midvale Soils are less developed than surface soils formed in similar deposits of equivalent age. The degree of development of B and Cca horizons in these surface soils, which are formed in alluvial, eolian, and lacustrine deposits about 11,000-16,000 years old, appears to be more closely related to the thickness and texture of the parent material and to climatic factors than to mineralogy or relative age of the parent material.

5. Review of the relatively few studies of the quantitative relationship between rock weathering and time, together with our extensive study of weathering rinds on volcanic clasts in Quaternary deposits, allows some general conclusions about rock-weathering rates. It appears that, with the exception of congruent dissolution, the development of most rock-weathering features is <u>not</u> a linear function of time. Some processes, such as hydration of volcanic glass, can be modeled both empirically and theoretically as diffusion processes, but most weathering features are complex and their time functions can be modeled only empirically, commonly as logarithmic functions of time.

6. Field mapping of the sequence of glacial and glaciofluvial deposits near Crested Butte, Colorado, reveals a sequence of four ages of deposits. In general, the youngest two deposits, both probably late Wisconsinan, are characterized by minimal rock weathering and relatively weak soils (A/Cox and A/cambic B/Cox profiles, respectively), whereas the older deposits are characterized by moderate to strong rock weathering and variable but generally well developed soils (Bt horizons common). However, a number of factors, including variable sedimentary parent materials; extensive fan, slopewash, and eolian deposition; and locally variable erosion make quantitative comparisons of relative-age parameters difficult.

Reports

Shroba, R. R., 1979, Rates of development of cambic and argillic B horizons and oxidized C horizons in Quaternary tills and periglacial deposits, Southern and Central Rocky Mountains: Agronomy Abstracts, Soil Science Society America Annual Meeting, 71st, p. 195.

Colman, S. M., and Pierce, K. L., 1979, Preliminary map showing Quaternary deposits and their dating potential in the conterminous United States (scale 1:7,500,000): U.S. Geological Survey Miscellaneous Investigations Map MF-1052.

Colman, S. M., 1979, Clay minerals in weathering rinds and implications for rates and mechanisms of B-horizon formation: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 404.

Birkeland, P. W., Colman, S. M., Burke, R. M., Shroba, R. R., and Meierding, T. C., 1979, Nomenclature of alpine glacial deposits--or what's in a name: Geology, v. 7, no. 11 (in press).

Uranium Series Dating

9740-00378

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Investigations

1. 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 900,000 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.

2. Uranium-trend techniques have been applied to estimate the rate of formation of caliche that exists in extensive, dense, and thick deposits. These type deposits form over a relatively long period of time and do not meet the criteria of short time of formation required for deposition of alluvial deposits that are not largely replaced by calcite. In this application, U-trend plots are constructed between adjacent samples of the material collected from the caliche unit which consisted of six separate samples cut from a vertical channel in the formation.

Results

1. East of Carlsbad, New Mexico, a unit of the Mescalero caliche and the overlying Berino soil were obtained and analyzed for uranium-trend dating. The samples from the caliche unit were sampled from a vertical channel with sample H in the uppermost part, consecutively decreasing in depth with sample letter identification to sample M at the base as shown in the data table below. A nearly pure $CaCO_3$ horizon, occurred near the middle of the unit and a sample of this horizon is identified as K_{CARB}.

Deposit	U-trend slope	X-intercept Th^{232} index	Half-period of $F_{(o)}$ (10^3 yr)	Age (10^3 yr)
Berino soil	- .601	-.313	190	350±60
Mescalero caliche = estimate of time of calcite replacement				
K→K carb	-2.27	+.0077	400	360
H, I→M	-7.39	-.0278	620	410
J→M	-2.18	-.0374	620	420
L→M	- .419	+.0731	260	510

Tephrochronology of the Western Region

9540-01947

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Summary

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

Investigations

Continued specific regional and topical tephrochronological studies (1-10) reported in Summaries of Technical Reports, Volume VIII, June 1979. Additional studies include:

1. Completed preliminary analyses of tephra from the late Cenozoic Malaga Cove section north of Palos Verdes Peninsula in southern California (with C. Meyer and P. Russell).

2. Obtained and analyzed by microprobe a suite of tephra samples from DSDP Leg 63, off the coast of Southern California (with C. M. Meyer).

3. Mapped, sampled, and analyzed four Pleistocene ashes along the north and south limbs of the Ventura Avenue anticline near the town of Ventura in southern coastal California, in a continuing study aimed at providing age calibration to the Quaternary section and structure in this area (with K. R. Lajoie and R. F. Yerkes).

4. Completed and processed to publication a report on correlation of late Cenozoic tephra units in central and northern California. This report includes a comparison of X-ray fluorescence and neutron activation analysis of volcanic glass in the chemical "fingerprinting" and correlation of tephra.

Results

1. Preliminary electron microprobe analyses of two superposed tuffs in the "Repetto" beds and underlying Malaga Formation north of Palos Verdes Peninsula, Los Angeles area, suggest that these tuffs correlate with the Nomlaki and Lawlor Tuffs, respectively, found in northern and central California.

Table 1. Partial analysis of volcanic glass of tuffs by electron microprobe. C.E. Meyer, analyst.

Tuff	Position	Color	Age (m.y.)	Al	Fe	Mg	Mn	Ca	Ba	Ti
Nomlaki Tuff	upper	white	3.3 (K-Ar)	6.43	0.68	0.10	0.04	0.64	0.08	0.11
Tuff in "Repetto" beds	upper	white	3.6 (F.T.)[1]	6.45	0.73	0.12	0.04	0.65	0.09	0.12
Lawlor Tuff	lower	gray	4.0-4.5 (K-Ar)	7.01	1.35	0.05	0.03	0.61	0.07	0.10
Tuff in Malaga Fm.	lower	gray	4.4 (F.T.)[1]	7.08	1.36	0.05	0.02	0.59	0.08	0.10

1. Fission-track ages determined on volcanic glass by Boellstorff and Steineck, 1975.

There is consistent agreement between correlative tuffs (table 1) with respect to stratigraphic position, color, isotopic ages, and major- and minor-element chemistry of the volcanic glass. More precise analyses of the volcanic glass by X-ray fluorescence and neutron activation analyses are now being run. If confirmed, outcrop localities of the same tuff will be correlated over a distance of more than 800 km, and enable correlation of marine and non-marine fauna of several separate basins.

2. Preliminary electron microprobe analyses by C.E. Meyer of 20 tephra samples obtained from Deep Sea Drilling Project Leg 63 have not resulted as yet in any specific correlations between the Cenozoic section beneath the ocean floor and on-land tephra samples collected in southern California and other western states. One of the DSDP tephra samples belongs to the Long Valley - Mono Glass Mountain family of ashes erupted east of the central Sierra Nevada, and should correlate with one of the ashes erupted during the last 0.7 to 1.2 m.y. from that area. A second tephra sample correlates with the Pearlette family of ashes from the Yellowstone area of Wyoming and Idaho, erupted during the period 0.6 to 2.0 m.y. ago, and should correlate with one of the Pearlette types. Further analyses are now in progress using an energy-dispersive X-ray fluorescence technique on thin powder films--an experimental technique designed to handle the small sample splits obtained.

3. Previous work (see Sarna-Wojcicki, Summaries of Technical Reports, Volume VI, June, 1978) has shown that six volcanic ashes, persistent time and stratigraphic markers, are present in the folded and faulted Quaternary marine section of the Ventura Avenue anticline north of the town of Ventura, and in the South Mountain area to the east. Four of these ashes have now been mapped along both the north and south limbs of the anticline, over a distance of 24 km. Stratigraphic relations between these ashes were previously inferred on the basis of partial, isolated sections and projections along strike, as well as from correlations of these ashes to the source area, the Long Valley - Mono Glass Mountain area east of the Central Nevada, where stratigraphic relations and ages of three of the ashes are known. Recent field work has disclosed all four ashes

within a continuous stratigraphic section on the north limb of the anticline, supporting earlier correlations.

The four ashes, from oldest to youngest, are correlated with the "Bailey" ash (1.2 $\pm$ 0.2 m.y.; Izett and others, 1974), the "Gray" ash (about 1.0 m.y.), the ash of "Mono Glass Mountain" (about 0.8 m.y.), and the Bishop ash (about 0.7 m.y.; Dalrymple and others, 1965).

The uppermost ash, the Bishop, is repeated and overturned above this section, where the Red Mountain fault is thrust over the north limb of the Ventura Avenue anticline. Involvement of this ash in the faulting suggests that the Red Mountain fault has been active since at least 0.7 m.y. b.p. Offset of late Pleistocene marine terraces, and seismicity geometrically associated with this fault (Yerkes and Lee, 1979), indicate it is active at present.

Reports

Sarna-Wojcicki, A. M., Bowman, H. W., and Russell, P. C., 1979, Chemical correlation of some late Cenozoic tuffs of northern and central California by neutron activation analysis of glass and comparison with X-ray fluorescence analysis. U.S. Geological Survey Professional Paper 1147, 15 p.

Sarna-Wojcicki, A. M., Bowman, H. W., Meyer, C. E., Russell, P. C., Asaro, Frank, Michael, Helen, Rowe, J. J., and Baedecker, P. A., Chemical analyses, correlations, and ages of late Cenozoic tephra units of east-central and southern California. U.S. Geological Survey Open-File Report (in review).

Quaternary Reference Core, Clear Lake, California

9950-02394

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Investigations

1. Procurement of drill rig and other equipment required for obtaining and analyzing the core to be taken from Clear Lake, California, in FY 80.

2. Analysis of sediments from Searles Lake core KM-3 in cooperation with G. I. Smith (USGS).

Results

1. The drill rig and other equipment have all been procured. The drill rig procurement presented considerable difficulty because of the large sum of money involved and the necessity of dealing with so many different groups and individuals. The rig is being purchased from Mobile Drilling Company and is to be delivered in late January 1980.

2. Grain-size analyses of samples from the Kerr-McGee core KM-3 from Searles Lake, California, were completed in cooperation with G. I. Smith and Joe Liddicoat (Lamont) by a summer student (Ms. Antoinette Lopez) hired on the Minority Participation in Earth Sciences Program. Preliminary analysis of the data shows a large number of bimodal populations that are interpreted as reflecting windblown sediments being added to the normal lacustrine sediments. Normal lacustrine sediments in Searles Lake have a mode at 7.7 ϕ (4.76 μm $\pm$ 1.11). The coarse, windblown fraction has a mode at 4.1 ϕ (57.47 μm $\pm$ 29.82). Complete analysis and a joint paper is anticipated.

Reports

Casteel, R. W., Williams, J. H., Throckmorton, C. K., Sims, J. D., and Adam, D. P., 1979, Fish remains from core 8, Clear Lake, Lake County, California: U.S. Geological Survey Open-File Report 79-1148, 98 p.

Paleoseismic Indicators in Sediments

9950-01294

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Investigations

1. Post-earthquake geologic study following 15 April 1979 Yugoslavian earthquake.

2. Detailed geologic mapping in San Andreas fault zone and vicinity.

3. Coring operations in sag ponds of the San Andreas and southern Calaveras faults.

4. Laboratory experiments on earthquake-induced structures in sediments.

5. Laboratory analysis and interpretation of cores from lake sediments: (1) Ancient Lake Cahuilla (Imperial Valley, Calif.); (2) Koehn Lake (Garlock Fault).

Results

1. J. D. Sims was the geologist member of the four-man team sent to Yugoslavia to study the effects of the 15 April 1979 earthquake. Geological observations of areas along the Adriatic Sea coast and inland were made in conjunction with members of the Institute of Seismological Engineering at Skopje, Yugoslavia. Observations suggest that significant long-term tectonic deformation of the coastline has occurred, resulting in several sets of uplifted coastal terraces. Two reports up uplift at the coastal town of Ulcinj and Budva associated with the 15 April earthquake are not verified. The reported uplift at Ulcinj, near the Yugoslavian-Albanian border is 60 cm, and at Budva as much as 1 meter.

D. M. Boore and I are preparing a joint paper on the preliminary seismologic and geologic analysis of the earthquake. This work has resulted in a relocation of the earthquake and fault plane solution using WWSN data.

2. Continued detailed geologic mapping of the San Andreas fault zone along Mustang Ridge, Monterey County, California by M. J. Rymer has delineated subsidiary faults within the fault zone that may be partly relieving the stress buildup along the fault. The main trace in this area is characterized by relatively straight segments, ranging in length from approximately 0.8 to 3.0 km, that are separated by steps and bends. The steps, along with the bends, accomodate variations in the trend of the main trace of as much as 20°. Features that suggest the recency of movement along the main trace include scarps, springs, sag ponds, and offset drainages. However, all of these features are also present along the subsidiary faults. In fact, 70 percent of

the sag ponds mapped in the area are located along subsidiary faults and not along the main trace. The subsidiary faults are characterized by straight and slightly curved traces with generally down-to-the-west normal offsets whose scarp morphologies suggest Holocene activity. Subsidiary faults have angles of incidence with the main trace of from 21° to 72°. These angles of incidence are greatest in the northwest part of the mapped section, where the fault zone is at its narrowest point. The subsidiary faults and their recency of (or continued) activity should be taken into account when alignment arrays or other methods of studying creep and movement in the area are set up.

3. Attempts were made to core selected sag ponds along the San Andreas fault on Mustang Ridge and near Searsville Reservoir, Stanford, California. Cores recovered to date are inadequate for determining seismic histories of the areas because of the short length of the cores; however, the cores are helpful in gaining an understanding of depositional processes in these ponds. Examination of the present cores shows that cored sag ponds on Mustang Ridge contain virtually no carbon-dateable material, but the sag pond near Searsville Reservoir has abundant material in its sediment. Work is underway to correct techniques and equipment that cause the short core recovery problem and to locate more prime sag ponds for future coring and trenching.

4. Laboratory experiments have progressed slowly because of delays in the delivery of equipment. Everything but pressure transducers has now been delivered. However, no system operation check can be performed until the transucers are delivered and installed. This part of the project receives the smallest amount of attention owing to manpower and money shortages.

5. The laboratory analysis and interpretation of cores and lake sediments consists of two phases: (1) core splitting, description, and sampling, and (2) interpretation of X-ray radiographs and sediment analyses. We have now caught up on our back-log of cores to be split, described, and sampled. Preliminary interpretations of the X-ray radiographs has also been completed. We are now working on sediment analysis and interpretation,which is greatly backlogged. These analyses are critical to understanding depositional history and liquefaction potential.

Cores from Koehn Lake, California, bounded by the Garlock fault were analyzed in cooperation with Malcolm Clark. The cores were thought to be of moderate quality and recovery. However, X-ray radiography revealed that they contained less than 20 percent recovery and much of that showed varying degrees of deformation due to drilling. The drilling deformation prevented the identification of earthquake-induced deformation.

Reports

Calzia, J. P. and Sims, J. D., 1979, Deformational structures in Pliocene Bouse Formation near Vidal, Southeastern California: American Association of Petroleum Geologists Bulletin, v. 63, p. 427-428.

STUDY OF EARTHQUAKE RECURRENCE INTERVALS ON THE WASATCH FAULT, UTAH

U.S.G.S. Contract No. 14-08-0001-16827

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Summary of Third Semi-Annual Technical Report, October, 1979

INVESTIGATIONS

Detailed geologic studies that include mapping of the Quaternary deposits, topographic profiling of displaced geomorphic surfaces, and trenching have been completed at two locations along the Wasatch fault: the Kaysville site, which is 32 km north of Salt Lake City, and the Hobble Creek site, 28 km southeast of Provo. Investigations at a third site near the mouth of Little Cottonwood Canyon 13 km south of Salt Lake City are currently in progress. Data on the cumulative displacement of late Quaternary deposits, the number of surface faulting events, and the amount of displacement per event have been collected at these sites in order to estimate the magnitude of past surface faulting events and the frequency of recurrence of these events on individual segments of the fault zone and to estimate the recurrence of moderate to large magnitude earthquakes along the entire Wasatach fault.

RESULTS

Site Investigations

Kaysville Site: A minimum of three surface faulting events have produced a cumulative net vertical tectonic displacement of 10 to 11 m of an alluvial fan surface that is approximately 6,000 years old. The vertical tectonic displacements during the two most recent surface faulting events were between 1.7 and 3.7 m per event. The interval between these events was not less than 500 years or more than 1,000 years. The late Holocene slip rate along the segment of the fault at Kaysville was 1.8 mm per year and the average recurrence interval was probably closer to 1,000 years.

Hobble Creek Site: During the past 12,000 years at least six and possibly seven surface faulting events have produced 11.5 to 13.5 m of net vertical tectonic displacement at the Hobble Creek site. The average vertical tectonic displacement per event is between 0.8 and 2.8 m. The Holocene slip rate is 1.1 mm per year and the average recurrence interval is between 1,500 and 2,400 years.

Little Cottonwood Canyon Site: During the late Holocene at least two and possibly three surface faulting events have produced 10 to 11 m of vertical displacement on a trace of the main fault at the Little Cottonwood Canyon site. This displacement includes the effects of back-tilting and graben formation. Topographic profiles are being measured to assess the cumulative net tectonic displacement across the entire zone. A preliminary evaluation of the data suggests that the Holocene history of surface faulting at the Little Cottonwood site has been similar to the history of faulting at the Kaysville and Hobble Creek sites.

Magnitude of Past Surface Faulting Events

The displacement data from the Kaysville and Hobble Creek sites indicate that earthquakes in the magnitude range of 6 1/2 to 7 1/2 have occurred repeatedly along the fault segments at these sites. These estimates are based primarily on average values of the displacement per event; therefore, they may not necessarily represent the largest earthquake that has occurred on the Wasatch fault.

Earthquake Recurrence on the Wasatch Fault Zone

The recurrence of surface faulting earthquakes along the entire 370-kilometer-long fault zone is a function of the recurrence interval on the individual segments, the temporal and spacial distribution of events on different segments (fault behavior), and on the total number of segments that comprise the fault zone. If the recurrence intervals along the Kaysville and Hobble Creek segments of the fault (minimum of 500 years and maximum of 2,400 years per event) are representative of the recurrence intervals on all of the six to ten segments, and if the segments behave independently, the recurrence interval for the entire zone is one-sixth to one-tenth that of the individual segments, that is, between 50 and 400 years per event. No surface faulting events have occurred along the Wasatch fault zone during at least the past 132 years. This suggests a moderate to large magnitude surface faulting event (magnitude 6 1/2 and 7 1/2) is either due or past due somewhere along the Wasatch fault.

SELECTED REPORTS

Cluff, L. S., Swan, F. H., III, Schwartz, D. P., Hanson, K. L., and Knuepfer, P. L., 1978, Study of earthquake recurrence intervals on the Wasatch fault, Utah: U.S. Geological Survey, National Earthquake Hazards Reduction Program, Summaries of Technical Reports, v. VII, p. 115-117.

Cluff, L. S., Patwardhan, A. S., and Coppersmith, K. J., 1979, Estimating the probability of occurrence of surface faulting earthquakes on the Wasatch fault zone, Utah: to be published in the Proceedings of Conference on Earthquake

Hazards Along the Wasatch Front and in the Reno-Carson City Area (U.S. Geological Survey, Open-File Report).

Cluff, L. S., Patwardhan, A. S., and Coppersmith, K. J., 1979-80, Estimating the probability of occurrence of surface faulting earthquakes on the Wasatch fault zone, Utah: submitted to Bulletin of the Seismological Society of America.

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

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

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

Swan, F. H., III, Schwartz, D. P., Hanson, K. L., Knuepfer, P. L., and Cluff, L. S., 1979a, Recurrence of surface faulting and large magnitude earthquakes along the Wasatch fault zone, Utah: Geological Society of America Abstracts with Programs, v. 11, no. 3, p. 131.

Swan, F. H., Schwartz, D. P., Cluff, L. S., Hanson, K. L., and Knuepfer, P. L., 1979b, Study of earthquake recurrence intervals on the Wasatch fault at the Hobble Creek site, Utah: U.S. Geological Survey, Open-File Report, 40 p. (in press).

Swan, F. H., Schwartz, D. P., Hanson, K. L., Knuepfer, P. L., and Cluff, L. S., 1979c, Study of earthquake recurrence intervals on the Wasatch fault at the Kaysville site, Utah: U.S. Geological Survey, Open-File Report, 33 p. (in press).

Swan, F. H., Schwartz, D. P., and Cluff, L. S., 1979d, Recurrence of surface faulting and moderate to large magnitude earthquakes on the Wasatch fault zone at the Kaysville and Hobble Creek sites, Utah: to be published in Proceedings of Conference on Earthquake Hazards Along the Wasatch Front and in the Reno-Carson City Area (U.S. Geological Survey, Open-File Report).

Swan, F. H., Schwartz, D. P., and Cluff, L. S., 1979-80, Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault, Utah: submitted to Bulletin of the Seismological Society of America.

Tectonic Analysis of Active Faults

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Investigations

Young fault scarps were examined and profiles were measured along the Sulphur Springs and Simpson Park Ranges and the Cortez Mountains and in Carrico Lake Valley, north central Nevada. This completed a reconnaissance of all young fault scarps in the study area between 116° and 118° 30' W. long. and 40° 41° N. lat.

Results

The fault bounding the northwest side of the Cortez Mountain has broken in three discrete segments, despite the fact that the entire range front is clearly fault generated and displays a continuous set of faceted spurs hundreds of meters high along the entire front. The northeasternmost segment broke probably within the last 2,000 years, and perhaps as recently as a few hundred years ago. Only short remnants of young scarps are preserved in the middle segment of the range front, and along most of the middle segment, no young scarps are preserved. The age of the southwestern segments of the scarp appears to be Holocene. Young scarps are preserved in Crescent Valley north of the northeastern end of the young scarp along the southwestern segment of the range front. Perhaps faulting produced during the last seismic event along the southwestern segment diverged from the range front and passed into the valley area, but the scarps in the valley may be merely lurch features.

The scarp along the western flank of the Sulphur Spring Range appears to have considerable antiguity and may be of early Pleistocene or older age. Valleys as deep as 30 m are incised into the youngest scarps and adjacent original surfaces broken by the scarps, so that the scarps now cross terraces or benches, but are not found on the walls or valley bottoms of modern drainage channels.

A few of the scarps on the north side of the Simpson Park Range have slopes and other characteristics suggesting a Holocene age, but others appear older and some supported on bedrock could be as old as Pliocene.

In Carrico Lake Valley fault scarps apparently of a variety of ages are preserved, the youngest of which has characteristics of a Holocene age.

Reports

Wallace, R. E., 1979, Earthquakes and prefractured state of the western part of the North American content: Research Conference on Intracontinental Earthquakes, Ohrid, Yugoslavia, 1976, Proceedings, (in press).

Wallace, R. E., 1979, Map of young fault scarps related to earthquakes in north-central Nevada: U.S. Geological Survey Open File 79-1554, scale 1:125,000, 2 sheets.

Wallace, R. E., 1979, Nomographs for estimating components of fault displacement from measured height of fault scarp: Bulletin of the Association of Engineering Geology (in press).

Wallace, R. E., 1979, Degredation of the Hebgen Lake fault scarps of 1959: Geology (in press).

Wallace, R. E., and Teng, T. L., 1979, Prediction of Sungpan-Pingwu earthquakes of August 1976: Bulletin Seismological Society of America (in press).

Jennings, Paul, C., editor, 1979, Report of the earthquake engineering and hazards reduction delegation to the Peoples Republic of China: Washington, D. C. National Academy of Sciences (in press.)

Wallace, R. E., 1979, Gilbert's studies of faults, scarps and earthquakes (abs.): Geological Society of America Abstracts with Programs, 1979 Annual Meeting, p. 534.

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

Contract No. 14-08-0001-16822

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INVESTIGATIONS

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

2. Analysis of the sedimentary deposits and associated fossils on the first marine terrace at Point Ano Nuevo to determine the history of formation of this broad, complex marine abrasional platform.

3. Analysis of the Frijoles fault complex to determine the late Pleistocene and Holocene history (displacement rates, recurrence intervals, recency of movement, etc.). The Frijoles fault complex is one of three primary traces of the San Gregorio fault zone, and consists of left stepping en echelon traces which exhibit both reverse and strike slip displacement.

RESULTS

1. Detailed mapping of the terrace stratigraphy and the Ano Nuevo thrust fault in sea cliff exposures along the south shore of Point Ano Nuevo and in an exploratory trench excavated across the fault indicates the following; 1) since the formation of the erosional platform of the terrace (105,000 years B.P.) the fault has experienced a minimum of six episodes of faulting that are recorded in the terrace stratigraphy. 2) each of these episodes of faulting resulted in 2.5 to 4.5 feet of vertical displacement accompanied by surface rupture and the formation of a scarp. 3) this is a minimum history, and it is highly probable that more than six faulting events have occurred over this time interval but that some were too small to have been preserved in the stratigraphic record. 4) the average recurrence interval for earthquakes having 2.5 to 4.5 feet of vertical displacement is approximately 16,000 years for the Ano Nuevo thrust fault. 5) exposures in the exploratory indicate that the fault offsets inter-dune pond deposits. This suggests Holocene movement along this fault.

2. We have collected fossil material from several locations at the base of the marine terrace at Point Ano Nuevo and have completed detailed stratigraphic sections within the marine terrace deposits. We are still waiting on amino acid dates which will allow us to determine how the abrasional platform of the terrace was formed.

3. Logging of the geology exposed in an abandoned quarry, the spillway for a damn, three exploratory trenches indicates; 1) the Frijoles fault is a complex zone of faulting that exhibits both right lateral strike slip and reverse components of movement. 2) the stratigraphy on the foot wall block indicates that there have been a minimum of eight episodes of colluvial deposition, probably off of a fault scarp, which exhibit very weakly developed soils. Each of these deposits indicates a faulting event that resulted in 3 to 4.5 feet of vertical displacement and the formation of surface rupture and a scarp. 3) since only less than half of the marine terrace deposits on the down thrown block are exposed, it is not unreasonable to assume that probably another seven or eight similar deposits lie buried, and that the fault has moved a minimum of 14 to 16 times in the past 105,000 years. 4) the average recurrence interval for earthquakes resulting in 3 to 4.5 feet of offset is approximately 5,000 to 7,000 years. 5) this is a minimum history, as smaller earthquakes were probably not preserved in the stratigraphic record on the downthrown block. 6) a fine to medium grained sand emplaced along the fault by liquifaction events has not aided in the development of an earthquake history. This is because there is no evidence that the liquifaction events commonly formed sand blows at the surface.

REPORTS

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

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

Revision and Studies of Modified Mercalli Intensity Scale

9950-02145

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Investigations

1. Work continues on review of the entire U.S. earthquake catalogue for larger events (I_0>V) and revision and (or) preparation of isoseismal maps. Work on this project has been coordinated with and supported a project in the Branch of Global Seismology aimed at the preparation of seismicity maps for all 50 states.

2. Attention has been focused on a careful investigation of the distribution of intensity for larger earthquakes of the Mississippi Valley (I_0≥VI) with the aim of: (a) developing attenuation relations for the area; and (b) identifying areas of anomalously high (or low) site response.

Results

1. In cooperation with Project 9-9920-01222 in the Branch of Global Seismology, five additional State seismicity maps have been issued as MF maps (Tennessee, Missouri, Illinois, Indiana and Ohio).

2. Attenuation relationships of the form $I-T_0=A+B\log r+Cr$ where I_0 is maximum intensity, I intensity, and r is distance have been developed using the larger earthquakes of the Mississippi Valley (I_0≥VI).

3. Isoseismal maps of the 1895 Missouri earthquake (I_0=VIII) and the 1968 Illinois earthquake (I_0=VII) show pronounced site amplification effects. There is good correlation of the site amplification effects shown by these earthquakes with the amplification effects found by G. Bollinger in his study of the 1886 Charleston South Carolina earthquake. An open-file report is being prepared.

Reports

Stover, C., Reagor, G., and Algermissen, S. T., 1979, Seismicity maps of the State of Illinois, U.S. Geological Survey, MF-1056.

Stover, C., Reagor, G., and Algermissen, S. T., 1979, Seismicity maps of the State of Missouri, U.S. Geological Survey, MF-1057.

Stover, C., Reagor, G., and Algermissen, S. T., 1979, Seismicity maps of the State of Indiana, U.S. Geological Survey, MF-1058.

Stover, C., Reagor, G., and Algermissen, S. T., 1979, Seismicity maps of the State of Ohio, U.S. Geological Survey, MF-1059.

Stover, C., Reagor, G., and Algermissen, S. T., 1979, Seismicity maps of the State of Tennessee, U.S. Geological Survey, MF-1081.

Regional and National Seismic Hazard and Risk Assessment

9950-01207

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Investigations

1. Considerable effort is being made to develop an efficient computer program for probabilistic ground motion calculations. The present programs that incorporate parameter uncertainty require large amounts of computer time.

2. The first of a series of meetings with geologists and seismologists from both within and outside the Survey was held with the aim of reviewing the geologic data available that might be useful in the refinement of seismogenic zones used in probabilistic hazard analysis. The United States has been broken into regions for these meetings.

3. Seismological data are being reviewed prior to the beginning of revision of the United States probabilistic acceleration map published by Algermissen and Perkins in 1976.

Results

1. A computer program for the calculation of probabilistic ground motion maps which includes parameter uncertainty has been developed (by modifying existing programs) that is four to five times faster than existing programs.

In cooperation with Project 9-9950-01917 (Outer Continental Shelf Seismic Risk) and Project 9-9950-02145 (Revision and Studies of Modified Mercalli Intensity Scale) attenuation curves for the eastern United States for velocity are being developed.

3. A meeting on the Great Basin area was held on Oct. 10 and 11, 1979, in Golden in which geologic data pertinent to probabilistic hazard mapping was reviewed. The meeting was very successful and a number of ideas for seismogenic zones, rates of occurrence of large earthquakes derived from geological data, etc., were presented. These data are being reviewed and analyzed with seismicity data in the Great Basin prior to the revision of the U.S. hazard map.

4. An open-file report, "Some Seismological Aspects of Nuclear Waste Disposal," is being prepared for review.

5. An open-file report, "Patterns of Late Quaternary Faulting in Western Utah and Its Application in Earthquake Hazard Evaluation," is in review and will appear in the Proceedings of the Alta, Utah, Conference on Earthquake Hazards along the Wasatch Front and in the Reno-Carson City, Nevada, area.

A NEW ATTEMPT AT SEISMIC ZONING MAPS FOR SOUTHERN CALIFORNIA

Contract No. 14-08-0001-17745

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The first semi-annual report summarized the work done under USGS Contract No. 14-08-0001-17745 from 22 December 1978 to 21 June 1979. The amount of the contract is $23,823. As was stated in the proposal, the initial effort under this study was to be the gathering together of geologic information relating to the relative and absolute degrees of activity of faults in the southern California area, and the subsequent effort would be to use these data together with seismological and historical information to produce a more realistic zoning map of southern California than has been available to date. During the report period, therefore, the principal effort was that of obtaining and collating geologic information, although admittedly the major effort of the project remains for the second half. During the initial six months, the Principal Investigator has talked with numerous local geologists -- particularly those involved in trenching studies -- and he has visited a few specific sites himself. It has become abundantly clear that faults categorized as "active" on existing maps (such as the California Division of Mines and Geology's 1975 "Fault Map of California") in fact represent a tremendous spread in degrees of activity and therefore in degrees of hazard. For example, in the Pasadena area, the Sierra Madre fault has had no movement on it within Holocene time, whereas the somewhat more innocuous-looking Raymond fault has had at least 3 major ground-displacement earthquakes during the same time period. Yet both have usually been considered equally hazardous on existing zoning maps that use active faults as a zoning parameter.

The M = 5.2 Homestead Valley earthquake of 15 March 1979, which was investigated in the field by the Principal Investigator and CIT students (among others), demonstrated once again the fallacy of attempting to estimate local seismic hazard on the basis of a seismographic or historic record as short as that of southern California (or most other parts of the world!). The Homestead Valley area was not an area characterized by abundant earlier recorded activity, and it is doubted that even the most sophisticated of statistical techniques would have identified the particular area as being more hazardous than most of the rest of southern California. During the earthquake, however, ground rupture did occur on two faults that had been mapped previously by Dibblee and had been shown by him as breaking Quaternary rocks. Field evidence observed by the CIT group, moreover, suggested Holocene displacement on at least one of the breaks.

The major effort under this contract remains to be carried out. In particular, the choice of the exact parameters by which the geologic information will be incorporated into the zoning procedure has yet to be worked out. During the first 6 months, considerable international literature relating to this problem has been collected and digested, but the hard decisions are yet to be made.

Physical Constraints on Source of Ground Motion

9940-01915

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Investigations

1. Stochastic fault modeling.

2. Elastodynamic source theory.

3. Analysis of ground motion records.

4. San Onofre site review.

Results

1. The paper "A Stochastic Fault Model," previously approved by the Director, has been revised extensively.

2. A paper with Mike Raugh "Elastodynamic Sources and Fields" has been completed and is in internal review.

3. Mike Raugh has begun analysis of ground motion records with the objective of characterizing statistical properties of high frequency motion.

4. The utility's consultant's report on expected ground motion at San Onofre Units 2 and 3 was reviewed for the Nuclear Regulatory Commission.

3-D Near Field Modeling and Strong Ground Motion Prediction in a Layed Medium

9940-02410

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The purpose of this project is to determine the ground motion in the vicinity of an earthquake. We intend to evaluate those parameters that can severely affect the ground motion by simulating earthquakes numerically. The parameters under study are the stress state on the fault, types of faulting (strike-slip and dip-slip) and the geological properties of the medium.

Investigations

1. Using a finite element method we have simulated near field ground motion from a thrust fault in two dimensions.

2. An analysis of the six, three-component, strong ground motion records from August 6, 1979 Coyote Lake earthquake has begun to determine the dynamic characteristics of the main shock.

3. Finite element simulations of the Coyote Lake earthquake have been started.

4. An analysis of how the structure of the Santa Clara valley has effected the near-field recordings of ground motion from the main shock and after-shocks of the Coyote Lake earthquake has started.

5. Acquisition and utilization of a numerical program for computing Green's function in a medium that not only allows for layering, but also for velocity gradients within layers has been completed.

Results

1. As expected from earlier work on strike-slip earthquakes, the thrust earthquake simulations show a definite increase in slip velocity amplitudes in the direction of rupture propagation. The up-thrown block has higher amplitudes. More work on the numerics is necessary to incorporate skewed elements (parallelograms) into the program before proceeding to three dimensional simulations.

2. It is clear from the strong ground motion records that the rupture of the Coyote Lake earthquake propagated in a southerly direction from the hypocenter. Based on SV polarization vectors it appears that the hypocenter

is east of the Calaveras surface trace. Either lateral refraction or a bending fault plane (provided the surface trace is a true indication of the fault at depth).

3. Preliminary finite element analysis indicates that a vertical velocity structure is absolutely necessary to attain any agreement between recorded and synthetic ground motion.

4. We have demonstrated that the vertical phase that produced the highest recorded acceleration most likely results from a converted S to P at the base of shallow sediments.

5. We have incorporated a new Green's function program into our method for computing ground motion. The new program (developed by Allan Olson at the Inst. of Geophys. and Planet. Phys., Univ. of Cal., San Diego) not only allows for vertically homogeneous layers, but also permits for velocity gradients.

Reports

Archuleta, R. J. and Day, S. M., Dynamic rupture in a layered medium: an example, the 1966 Parkfield Earthquake, submitted for publication.

Angstman, B., Spudich, P. and Fletcher, J., The Coyote Lake earthquake: 0.42g acceleration from an S-P converted phase, abstract, 1979 AGU Fall Meeting.

Archuleta, R. J., Rupture propagation effects in the Coyote Lake earthquake, abstract, 1979 AGU Fall Meeting.

EARTHQUAKE SOURCE MODELS INFERRED FROM LONG AND SHORT PERIOD TELESEISMIC OBSERVATIONS

by

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Summary of Final Contract Report

27 January 1978 to 31 May 1979

Contract No. 14-08-0001-16793

Objective

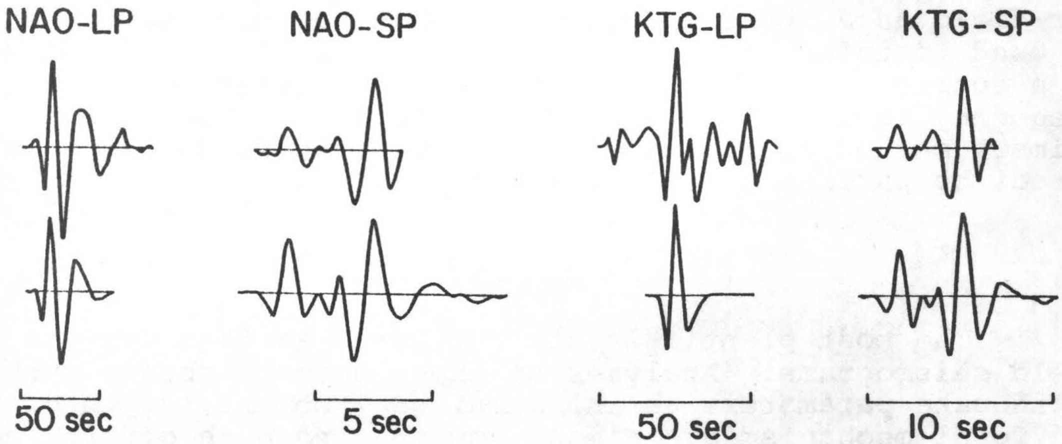
The objective of this research project is to determine the extent to which the earthquake source can be constrained by far-field observations. The ultimate issue is whether the far-field data, particularly the short period recordings, can be used to infer the main characteristics of the earthquake as a source of strong ground motions, at least for the common frequency band ($f < 2$ Hz). For achieving the objective our primary method is computation of synthetic seismograms for direct comparison to the observations.

Summary

The most plentiful data for large earthquakes are far-field seismograms. Analyses of these data to obtain such earthquake parameters as the magnitude, moment, depth of focus and focal mechanism are almost routine and much effort has been expended to find the relationship of strong ground motion to these parameters. However, events that are similar in terms of these gross source parameters can have quite different dynamic characteristics, and, as a result, different strong motion. These differences can only be deduced by more detailed analysis of the recorded ground motions.

Seismograms from teleseismic distances ($\Delta > 30°$) are less influenced by characteristics of the travel path than those from closer distances. In several recent studies synthetic long period body waves have been compared to the observations to obtain more detailed information about the source. We extend this technique by studying both long and short period P wave recordings. The teleseismic P wave recordings of six earthquakes were collected and digitized. These are: (1) 1975 Pocatello Valley, (2) 1975 Yellowstone Park, (3) 1968 Borrego Mountain, (4) 1975 Oroville, (5) 1976 Gazli and (6) 1977 Romania.

Detailed synthetic seismogram studies were done for the first, third and fourth events on the list. Our most complete study is of the Pocatello Valley event. The focal plane is constrained by observations of P wave first motions and the well-mapped aftershock sequence. Comparison of synthetic and observed seismograms indicate that to simultaneously fit the long and short period P waves, the source model must begin with a relatively small region of high stress drop/rupture velocity, then move into a region where these parameters are smaller that adds to the long period radiation while being a weak source of high frequency waves. The synthetic seismograms were computed with the Archambeau/Minster source model and with a three-dimensional finite difference calculation of constant effective stress faulting on a rectangular fault plane. The two source models are thereby compared, helping to interpret the physical meaning of parameters deduced with the Archambeau/ Minster source. A typical comparison with observed (top) records is shown below.



The agreement is good for the first five to eight seconds, which is all that is attempted. Our estimate for the stress drop at rupture initiation is 50 bars. This is an order of magnitude lower than our estimate for the 1971 San Fernando earthquake (under a previous USGS contract) using the same methods.

The Yellowstone Park earthquake was a nearby event, superficially quite similar to the Pocatello Valley event. However, examination of the long and short period teleseismic P waves suggests that this event was much more complex, perhaps indicating a highly variable stress drop.

The 1968 Borrego Mountain and 1975 Oroville earthquakes are events for which source models have been proposed that provide a reasonable fit to the long period teleseismic P waves. However, unlike the San Fernando and Pocatello Valley events, the model fitting the long period P gives poor agreement with the short period P wave, no matter how we vary the parameters controlling the source time history. This failure to fit the data might be due to the fault plane orientation being incorrect for the initiation of rupture or to failure of our models to properly account for details of the rupture dynamics or local geology. We believe it is possible to fit the short period data with models not much more complex than those we used, but were unable to make the effort required to find satisfactory models.

As an independent check on the validity of the source model inferred for teleseismic data for the Pocatello Valley event, we computed synthetic displacement, velocity and acceleration seismograms and response spectra at many locations from 150 to 180 kilometers. The crustal velocity profile, attenuation, source orientation, depth and magnitude were varied to indicate the range of ground motions predicted. Our predictions for the peak motions are found to fall within the bounds outlined by a number of empirical studies of ground motions at these ranges.

The report also includes the mathematical formulation for computing the far field and near field radiation from a growing and propagating relaxation source based on the Archambeau/Minster source theory. This formulation allows arbitrary specification of the rupture velocity and stress drop as a function of rupture growth and has been convenient for some of our earthquake modeling studies.

Interactive Data Processing Center for Ground Motion Studies

9940-02085

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Investigations

The interactive data processing center provides investigators with a convenient, state-of-the-art tool for studies of earthquake sources, wave propagation, ground response, and strong motion. Projects hosted include field investigations of major earthquakes, routine processing for permanent installations, and studies of synthetic earthquakes. Incoming field data is transferred to on-line disk storage from several digital playback units (through parallel and serial interfaces), from in-house digitizers (through cards or IBM-compatible floppy disk), and from outside sources (on 9-track magnetic tape). Using familiar, FORTRAN techniques, real and synthetic data are analyzed, printed on terminals and line-printers, or displayed on Tektronix, Versatec, and CalComp plotters.

Results

The interactive data processing center consists of a Digital Equipment Corp. PDP-11/70 minicomputer and associated peripherals running under the vendor-supplied real-time operating system, RSX-11M. Center personnel are responsible for the maintenance of the system and software for routine processing of strong motion records.

(1) Software

The following programs have been developed or modified to run on the PDP-11/70:

1. DR11K - Sprengnether DR100 playback (using interrupt-driven DR11-K parallel interface).

2. DR100 - Removes time marks; plots; and allows P and S wave picking of DR100 data.

3. DRSPEC - Plots power spectra of DR100 output.

4. HYPOINVERSE - Solves for hypocenter locations.

5. EPIMAP - Plots epicenters or hypocenters and station locations with a Mercator or Lambert Conformal projection.

6. HPLT - Plots epicenters or hypocenters with variable plane of projection.

7. MFRAC - Calculates interactions between fractures; gives stress and displacement fields.

8. PH2RSX - CalTech Volume II processing of strong motion data: correction, filtering and integration of ground acceleration. (Work in progress on other components in the CalTech series.)

9. GRNPLOT - Computes theoretical seismograms for point double couple earthquake sources in layered earth structures.

Also, software for the CalComp 1051 plotter has been integrated into the plotting package providing identical CalComp-style calls for all devices connected to the system.

(2) Hardware

Hardware additions to the system include a dual-density IBM-compatible floppy disk system (for reading digitized records), a second 9-track tape drive, an on-line 33" CalComp drum plotter, and several smaller items such as terminals and modems.

(3) Data

Recently acquired data includes studies of seismicity around the Monticello Reservoir in South Carolina (a site of probable induced seismicity), and aftershock activity of the August 6, 1979 Coyote Lake earthquake.

Reports

None

Development and Acquisition of Instrumentation for the Ground Motion Program

9940-02409

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Investigations

Evaluate and conduct preliminary field tests on a prototype general earthquake observation system (GEOS-I).

Results

The GEOS-I system was developed for application to a wide variety of both active and passive seismic experiments ranging from strong motion to teleseismic studies. System specifications include: central CPU control of all system modules; 16 bit/96 db (12 bit/66 db optional) dynamic range: selectable digitization rate (1-1200 sps)/frequency response (20 sec-600 Hz); selectable sensor type on 1-6 channels; 22 megabit four-track recording capacity on cartridge recorder in ANSI standard computer compatible format; low-power (1 watt quiescent); direct data playback via RS-232 port to computer, telemetry system or analog chart recorder; software loading from DEC 11/70 cross-compiler, tape cartridge, or EPROM; automatic external time sync, calibration, and system status via watchdog functions; and self-prompting English language instructions via 32-character display for simple instrument set-up and operation.

Preliminary field tests indicate prototype meets initial design specifications. Minor software/hardware modifications are continuing to simplify instrument operation and maintenance. Spectra obtained from field recordings on the prototype show clearly the advantages of the 16 bit, 1200 s/sec, 20 sec-600 Hz features.

Reports

None

Dynamic Soil Behavior

9550-01630

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Investigations

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

2. Continued an analytical study on the torsional response of cylindrical soil specimens.

Results

1. Undrained cyclic loading of San Francisco Bay mud, carried out to strains of several percent, has demonstrated the effects of three-dimensional loading to be significant. The shear modulus for both loading and unloading and the damping ratio were measured during cyclic loading along different paths in the deviatoric plane. The pore pressures generated were also monitored.

2. Theoretical calculations have suggested that the equivalent radius used to interpret shear modulus from high-strain torsional tests of solid soil specimens ranges between 0.75 and 1.0 times the outside specimen radius whereas the current recommended ratio is 0.67. In addition, the maximum hysteretic damping calculated for soils with nonlinear behavior of the Masing type is found to be 0.637 in contrast with the value of 0.30 widely assumed.

Reports

Chen, A. T. F., and Stokoe, K. H., II, 1979, Interpretation of strain-dependent modulus and damping from torsional soil tests: Available from National Technical Information Service, Springfield, Va, 22161, NTIS-PB-298479, June, 45 p.

Chen, A. T. F., 1979, DITT--A computer program for data interpretation for torsional tests: U.S. Geological Survey Open-File Report 79-1463, 23 p.

Ko, H. Y., and Strickland, Jere, 1979, Soil behavior under three-dimensional cyclic loading [abs.], in Society of Engineering Science, 16th, Northwestern University, September 1979, Proceedings: p. 7.

Chen, A. T. F., and Stokoe, K. H., II, 1979, Strain-dependent modulus and damping from torsional soil tests [abs.], in Society of Engineering Science, 16th, Northwestern University, Proceedings, p. 7. (Paper presented at the meeting.)

The Influence of Local Site Geology on Strong Ground Motions

14-08-0001-17776

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Objective

The objective of this study is to construct an improved analytical procedure for modeling local site response to earthquake ground motion. In particular, two-dimensional, nonlinear soil response is included in the treatment. The work consists of two phases: (a) development of a two-dimensional characterization of the earthquake input motion, and (b) two-dimensional numerical simulation of the site response, using a recently developed endochronic constitutive theory to represent soil behavior.

Investigations

1. Strong motion recordings for earthquakes do not provide a description of the local spatial variation of ground motion. Therefore, a synthetic seismogram method has been assembled to characterize the incoming wavefield for a given site.

2. A new endochronic model of soil behavior has been developed, which provides substantial improvement over the original version.

Results

1. An algorithm has been programmed for synthesizing the SH portion of the incident seismic disturbance at a given site and approximating it as a sum of plane waves with varying angles of emergence.

2. A new endochronic theory for soils has been developed. The new theory can describe many important features of soil response, including densification, strain hardening and softening, hysteresis, and creep under cyclic loading. It correctly predicts observed soil behavior for small unloading and reloading from a prestressed condition. A subroutine has been programmed for the case of simple shear, and has been applied to model cyclic shear in dry sand. Very accurate agreement has been demonstrated with available data for dry sand, out to 300 loading/unloading cycles. The subroutine, together with the dry sand model, will be key ingredients in the calculations of local site response.

Reports

Valanis, K. C., and Read, H. E., 1979, An endochronic plasticity theory exhibiting absolute hysteresis loop closure, Abstract of paper to be presented at the International Symposium on Soils Under Cyclic and Transient Loading, Swansea, UK.

Seismic Wave Attenuation in Conterminous United States

9950-01205

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Investigations

1. Data reduction and analysis of 20 earthquakes and 55 quarry blasts recorded at distances of about 20 km to 350 km in the northeastern United States is in progress.

2. Data reduction and analysis of 31 NTS events recorded on strong motion instruments in the distance range of between 1 and 20 km is in progress.

3. Continuation of regional compilation of seismograms for selected small earthquakes in the United States, to be used in the regional seismic-wave attenuation study, is in progress.

4. Continuation on the attenuation study for displacement (cm) from 63 earthquakes recorded in the western United States by strong-motion instruments is in progress.

5. Data reduction, tabulation and analysis of seismograms recorded in different geological environments in the United States from 36 earthquakes is in progress.

Results

1. An empirical magnitude scaling law (M_L) has been derived, using the maximum horizontal acceleration recorded on strong-motion instruments (see Figure 1).

2. The M_L values determined in the above study from 63 earthquakes are consistent with those M_L values assigned by the Pasadena and Berkeley seismological stations.

3. The mean M_L values obtained using the empirical scaling law derived from accelerograms are in excellent agreement with those M_L values for the same 40 earthquakes that were determined by a different procedure by Kanamori and Jennings (1978).

4. An empirical magnitude scaling law using the maximum particle velocity (cm/sec) as a function of distance at intermediate epicentral distances has been derived and tested, and is being published. The derivation of this empirical magnitude scaling law for the western United States partly fulfills the objectives of determining regional attenuation curves for the United

States. Furthermore, these attenuation relations yield the basis for determining the size of an earthquake in different regions, and thus provide a "calibration" from which magnitudes determined elsewhere can be related to M_L magnitudes in the west.

5. Preliminary attenuation curves for the northeastern United States using weak ground motion recordings and quarry blasts are being revised. Further work is in progress using Pg and Lg phases.

Reports

Espinosa, A. F., Chiburis, E., and Cicerone, R., 1979, Preliminary attenuation study of Lg in the northeastern United States: (in preparation).

Chiburis, E., Espinosa, A. F., and Cicerone, R., 1979, Preliminary attenuation study of Pg in the New England area (in preparation).

Espinosa, A. F., 1979, Horizontal particle velocity and its relation to magnitude in the western United States: Seismological Society of America Bulletin, Vol. 69, 2037-2061.

Espinosa, A. F., 1980, Attenuation of strong horizontal ground acceleration in the western United States: Seismological Society of America (in press).

Espinosa, A. F., and Zambresky, Liana, 1980, Attenuation curves for ten historical earthquakes in the United States (in preparation).

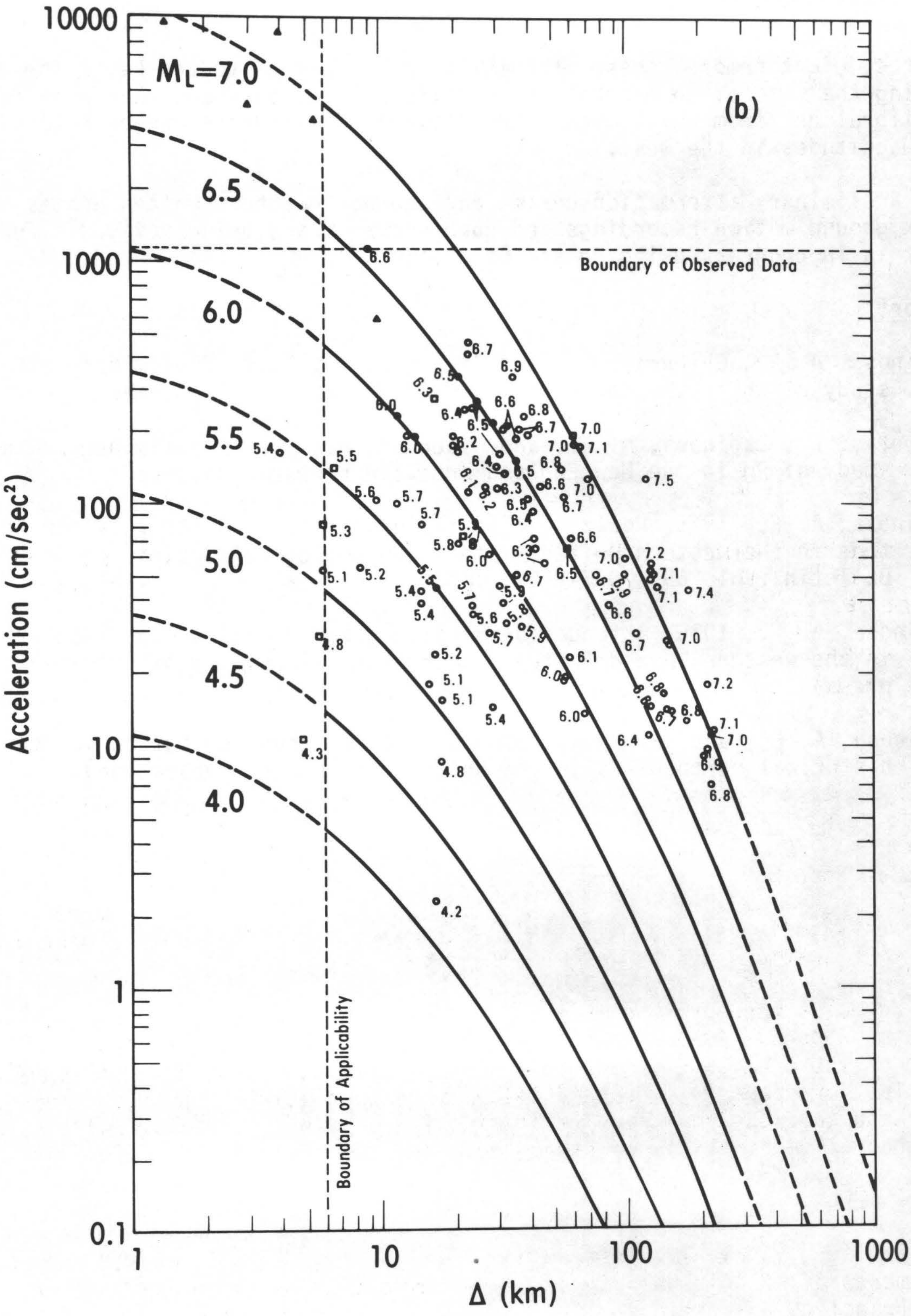

Figure 1. Attenuation of horizontal ground acceleration for local magnitude (M_L) events. The data used in this figure is from 63 earthquakes recorded on strong-motion in the western United States (For more details, see Espinosa, 1980). Boundary of applicability and boundary of observed data is shown in this figure.

Regional Shear Wave Studies

9940-02087

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Investigations

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

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

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

Results

1. Measured shear-wave velocities were used to develop a methodology for making improved seismic response maps of the San Francisco Bay region. The use of such data is illustrated for a small area at the southern end of San Francisco Bay (see Figure 1).

2. Twenty additional holes (total of 47) were drilled to enlarge the data base for zonation studies in the Los Angeles area.

3. Six holes were drilled at locations of strong motion records obtained from the 6 August 1979 Coyote Lake earthquake. Four were drilled to a depth of 100 feet, one to 200 feet and at location #2 (motel) a deep hole (500 feet or deeper) is being drilled. These holes will be logged for shear and compressional wave velocities to provide site characteristics for theoretical analysis of strong motion records.

Report

Gibbs, J. F., Fumal, T. E., and Borcherdt, R. D., (1980), In-situ measurements of seismic velocities for seismic zonation studies in the San Francisco Bay region, Bull. Seism. Soc. Am. (in press).

Gibbs, J. F., and Fumal, T. E., 1978, Identification and mapping of seismically distinct geologic units [abs.]: Earthquake Notes (Seismological Society of America), v. 49, no. 4, p. 52-53.

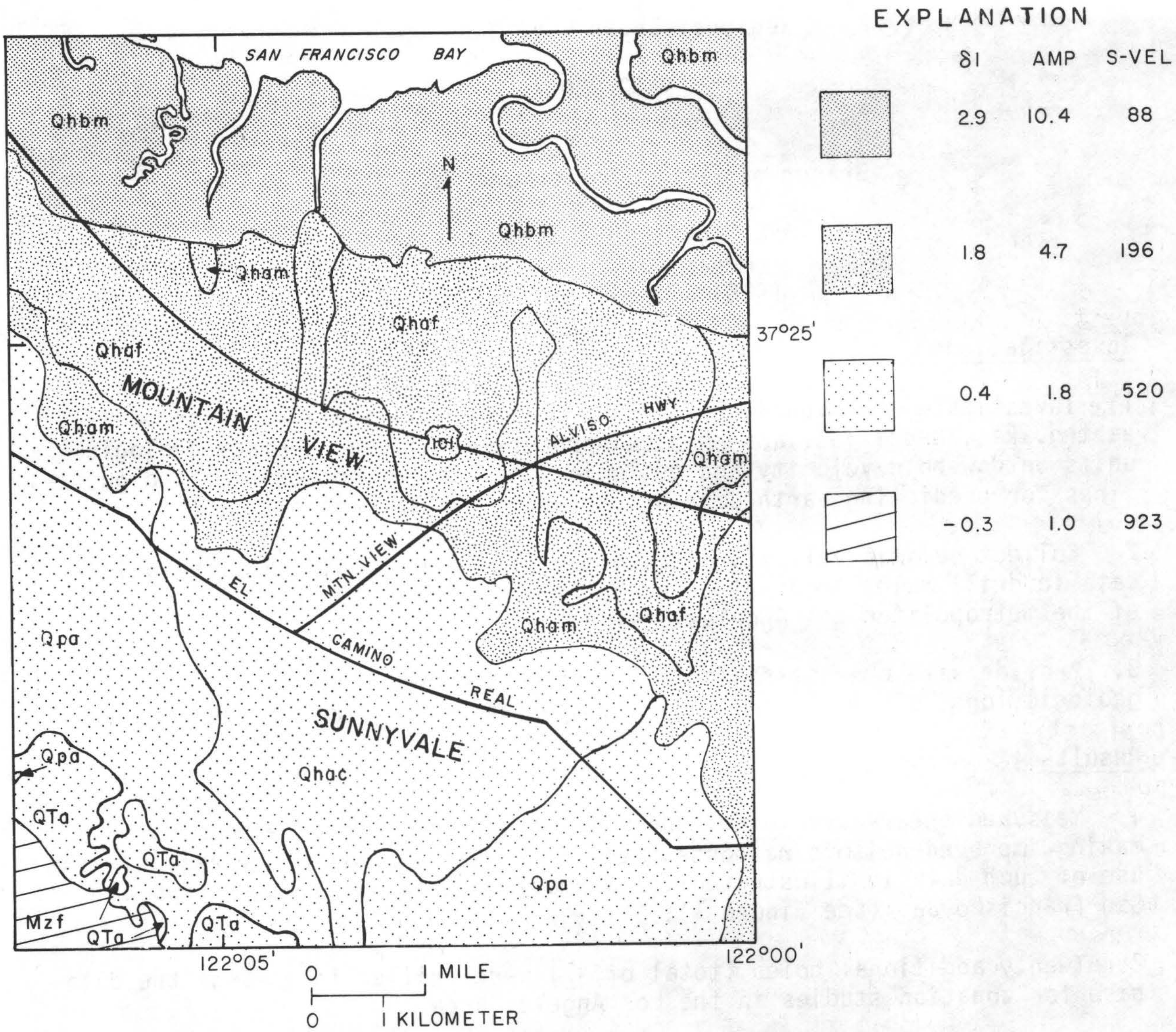

Figure 1. Geologic map of the Mountain View-Sunnyvale area showing the relative seismic susceptibility of the geologic map units. Amplification (AMP) and intensity increments (δI) are predicted using the mean shear-wave velocity (S-VEL) determined for seismically distinct units. Qhbm, Holocene bay mud; Qhaf, Holocene fine-grained alluvium; Qham, Holocene medium-grained alluvium; Qhac, Holocene coarse-grained alluvium; Qpa, late Pleistocene alluvium, QTa, Pliocene and early Pleistocene alluvium, and Mzf, Mesozoic Franciscan Formation.

Numerical Modelling

9940-01896

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Investigations

1. Finite difference models of sedimentary basins exhibiting transverse isotropy surrounded by hard isotropic rock were developed to compute synthetic seismograms on the surface. The extent of focusing of earthquake energy above the basin may be inferred from these.

2. Finite difference models of earth regions containing cliffs were developed to find out how much energy was scattered from a cliff along the upper and lower surfaces when body waves impinged upon them.

Results

1. Preliminary results indicate that phase delays associated with vertical/horizontal phase velocity mismatches alter the arrival times of packets of energy compared to same geometric configurations in completely isotropic media.

2. Ratios of spectra for the scattered field with incident body wave spectra indicate that for vertically incident P-waves on a vertical cliff, two scattered Rayleigh waves on the low side of the cliff have 20% or more of the incident wave power at several frequencies of engineering interest, and even more power along the top plateau.

3. For incident SV waves on a vertical cliff, scattered Rayleigh waves on the valley floor have 15% or more of the incident power, and somewhat more on the upper plateau.

4. When the cliff is inclined rather than vertical, substantially less energy is converted to horizontally travelling Rayleigh waves.

5. Very little energy (<5% of source) is converted from body waves to other body waves moving spherically away from cliff corners.

Reports

Harmsen, S. C., and Harding, S. T., 1979, A comparison of thru numerical techniques for modelling P-SV wave propagation across slanting interfaces: Approved by Director.

Ground Response, Salt Lake City, Utah Region

9940-01919

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Investigations

1. Nuclear-explosion ground-motion measurements made at 18 locations in the Ogden, Utah area have been processed and analyzed to define the ground response at sites underlain by unconsolidated materials of varying thickness, grain size, and degree of water saturation.

2. Nuclear-explosion ground motions were recorded in August at 12 sites in the Cedar City, Utah area. Processing is incomplete.

3. Nuclear-explosion ground motions were recorded in September at 6 sites in the Logan, Utah area. One site also recorded the 1962 Cache Valley earthquake. After these data have been processed, site transfer functions can be derived for possible correlation with the damage distribution in the 1962 earthquake.

Results

1. The horizontal ground response, defined in terms of the average ratio of horizontal response spectra for adjacent sites underlain by rock and soil, varies by as much as a factor of 10 in the Salt Lake City-Ogden-Provo region. The ground response is similar in each urban area and correlates with the laterally varying thickness of the unconsolidated material and the contrast in acoustic impedance. These data provide a basis for constructing ground shaking hazard maps in each urban area.

Reports

Hays, W. W., Rogers, A. M., and King, K. W., 1979, Empirical data about local ground response: 2nd U.S. National Conference on Earthquake Engineering, Proceedings, Earthquake Engineering Research Institute, pp. 223-232.

Hays, W. W., Miller, R. D., and King, K. W., 1979, Research to define the ground shaking hazard along the Wasatch fault zone: Conference on Earthquake Hazards, Great Basin, Proceedings, U. S. Geological Survey Open-File Report (in press), 9 p.

Rogers, A. M., Tinsley, J. C., Hays, W. W., and King, K. W., 1979, Evaluation of the relation between near-surface geological units and ground response in the vicinity of Long Beach, Calif.: Seismological Society of America Bulletin, v. 69, pp. 1603-1622.

Ground Motion Prediction at Selected Strong-Motion Sites

9940-01168

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Investigations

1. Shallow refraction profiles and downhole P and S velocity surveys in the Chalome, Gilroy, and Taft areas to provide data for modeling strong motion records (R. E. Warrick, J. F. Gibbs, R. M. Hazlewood, and W. B. Joyner).

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

3. Statistical analysis of strong motion data (D. M. Boore, A. A. Oliver III, R. A. Page, and W. B. Joyner).

Results

1. A downhole P and S velocity survey was made to a depth of 295 feet at strong motion site no. 2 in the Chalome area. The results will aid in the interpretation of the refraction profiles previously shot in Chalome valley and will provide data for modeling the strong-motion records. Also in the Chalome area a 200-foot hole for velocity surveys was drilled at station number 5 and 100-foot holes at stations 8, 12, and Temblor. Work in other areas included a 200-foot hole at Taft and holes from 65 to 200 feet deep at the five sites of Gilroy strong motion array where records were obtained in the Coyote Lake earthquake.

Reports

Boore, D. M., Joyner, W. B., Oliver, A. A. III, and Page, R. A., 1980, Peak acceleration, velocity, and displacement from strong motion records: Seismological Society of America, accepted for publication.

Joyner, W. B., Porter, L. D., and Perez, Virgilio, 1979, Strong-motion records from the Coyote Lake earthquake, California [abs.]: American Geophysical Union, Fall Meeting.

Collection of Basic Geophysical Data for Seismic Zonation Studies

9940-02091

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Investigations

1. Salt Lake City Area Ground Response - Ground motions from N.T.S. nuclear events were recorded at two stations in Provo, Utah, ten stations in Cedar City, Utah, and six stations in the Logan, Utah, area. The Provo stations were a reoccupation of prior recording sites to establish repeatability. The Cedar City sites were recorded for completion of data in the area and as a contrast of soil conditions compared to the Salt Lake area. The Logan, Utah, set is given a transfer function that correlates with an existing earthquake triggered strong motion record.

2. Los Angeles Area Ground Response - We attempted to record an N.T.S. nuclear event with the Sprengnether systems in the northeastern L. A. area. Five sites in the area were instrumented with Department of Energy seismic equipment.

3. N.T.S. Nevada - Strong ground shaking was recorded at two sites underlain by alluvium and rock from a nuclear event. This project is a continuation of a previous experiment to establish the ground response for different levels of strain and ground motion.

Results

The primary emphasis during the past six months has been to obtain data from nuclear explosions while the equipment is available and to try to finalize the data set in the Wasatch fault zone and the Los Angeles areas. Good data have been obtained in all areas. Analysis is proceeding in each geographic area.

Reports

King, K. W., Hays, W. W., and Hamilton, L. A., 1979, Seismic wave attenuation study of the Snake River plain [abs.]: American Geophysical Union meeting, Dec. 3-7, 1979.

Hays, W. W., Rogers, A. M., and King, K. W., 1979, Empirical data about local ground response: 2nd U. S. National Conference on Earthquake Engineering, Stanford, California, Aug. 22-24, 1979, p. 223-232.

Hays, W. W., and King, K. W., 1979, An experiment to evaluate ground response during strong ground shaking [abs.]: Annual Meeting of the Seismological Society of America in Golden, Colorado, May 1979.

Hays, W. W., Miller, R. D., and King, K. W., 1979, Research to define the ground shaking hazard along the Wasatch fault zone, Utah: Proceedings of Conference on earthquake hazards in the Great Basin, U. S. Geological Survey Open-File Report (in press), 9 p.

Rogers, A. M., Tinsley, J. C., Hays, W. W., and King, K. W., 1979, Evaluation of the relation between near-surface geological units and ground response in the vicinity of Long Beach, California: Seismological Society of America Bulletin, v. 69, p. 1603-1622.

Microzonation of the Memphis, TN Area

Semi Annual Report - Summary
Contract No.17752

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September 10, 1979

The report consists of four functional topics which will have to be considered. These are:

(i) Geology of the surficial deposits

(ii) Seismology of the area under investigation

(iii) Response analysis

(iv) Preparation of zone maps

As this study will not be introducing any new data for the surficial geology of the Memphis area, we shall mostly use data which has already been published. The majority of the data concerning the Geophysical aspects has been extracted from "Relationships of Earthquakes and Geology in West Tennessee and Adjacent Areas" (Stearns & Wilson, 1972). This paper will essentially provide this study with the necessary background of the surficial geology.

With close collaboration with Local Engineering Consultants, we have obtained some boring logs which are expected to give an indication of the nature of the surficial deposits. As usual, we cannot expect these boreholes to give a true insight into the surficial geology (a true map could only be prepared by a costly ground-survey which is not within the scope of this study). We shall assign the physical properties necessary for a Response Analysis according to the soil type and also due to any in-situ test results.

The prediction of large earthquakes and their epicenters forms an essential part of this study. We have reviewed literature pertinent to the seismology of the Central United States. In situations where data was found to be either scarce or of a doubtful nature we have presented our own data based on the present 'State-of-the-Art' assumptions. The 1000 year earthquakes have been assigned and their expected intensities in the City of Memphis tabulated.

We have also prepared synthetic seismograms which are intended to be used in the Response Analysis. These synthetic seismograms do not necessarily depict any one particular earthquake but allow one to infer the magnitude of response of the soil layer to horizontal motion. All synthetic seismograms will not be randomly generated. They will display the necessary characteristics which are present in any true seismogram.

The Response Analysis will be performed by using the soil-profiles obtained from the boreholes. All the layers, with their assigned physical properties, will be investigated for their response to the various horizontal motions resulting from the synthetic seismograms. We shall be using a computer program which will consider reflection and refraction at the soil layer interfaces. This will allow us to predict the true ground motion which is to be expected from a bedrock motion input.

Once the expected ground motion has been formulated it is then possible to prepare maps indicating the following:-

(i) Zones showing qualitative estimates of ground response,

(ii) Zones showing the natural frequency of the soil layer,

(iii) Zones of liquefaction and subsidence potential,

(iv) Zones of landslide susceptibility.

Methodologies for Seismic Risk Assessment

9950-01733

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Investigations

1. Efficient methods of calculating Bayesian uncertainties in seismic hazard estimates have been applied to the San Francisco Bay area and to the northern Mississippi embayment region.

2. The Brune model for shear-wave spectra has been compared to strong motion observations during a large variety of earthquakes.

3. Temporal changes in seismic activity have been investigated using Chinese earthquake data and United States earthquake data.

4. The usefulness of several strong motion duration definitions have been examined.

Results

1. Acceleration values from seismic hazard calculations in the San Francisco Bay area have statistical uncertainties on the order of 0.2 to 0.4. The smallest uncertainties are found about 50 km from the major faults; larger values occur close to faults and at distances of 100 km or more, due to uncertainties in depth of energy release, seismicity, and mean acceleration (at both small and large distances).

2. Comparisons of the Brune model with available strong motion data indicates that the effective static stress drop for California earthquakes is on the order of 100 bars. This is true for San Fernando earthquake data, for a variety of earthquakes documented in the Caltech series (where typical stress drops are lower than 100 bars) and for the Oroville aftershock data (where topical stress drops are greater than 100 bars).

3. When rates of seismic activity in the future can be estimated well, seismic hazard calculations are quite accurate; this justifies the assumptions used in seismic risk analysis (Poisson arrivals, independent event sizes, and locations). When stationary models of seismicity are used with a short historical data base, and seismicity is periodic as in China, hazard calculations are less accurate but are on the conservative side. No periodicity of the type observed in Chinese seismicity (~300 year period) is observable in the United States' earthquake history.

4. The simple definitions of strong motion duration in vogue with seismologists and earthquake engineers are unpredictable, misleading, and useless for seismic hazard analyses of ground shaking.

Reports

McGuire, R. K., and Barnhard, T. P., 1979, The usefulness of ground motion duration in predicting the severity of seismic shaking: Proceedings, U.S. National Conference on Earthquake Engineering, August 1979, Stanford, California.

McGuire, R. K., and Barnhard, T. P., 1979, Four definitions of strong motion duration: their predictability and utility for seismic hazard analysis: U.S. Geological Survey Open-file Report 79-1515, 115 p.

McGuire, R. K., and Hanks, T. C., 1979, RMS acceleration and spectra of the San Fernando earthquake: submitted to the Seismological Society of America Bulletin.

Earthquake Intensity and Recurrence

9940-01784

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Investigations

1. Major errors have been discovered in the existing maps of seismic intensity of the 1906 California earthquake. The errors have been further investigated and documented, particularly along the earthquake fault zone and at localities on the San Francisco peninsula.

Results

1. Based on the detailed damage descriptions in the official Lawson report, the seismic intensities at localities within the 1906 earthquake fault zone (within 200 m of the fault rupture) were only Rossi-Forel VIII-IX, rather than the RF X rating that is shown on the Lawson maps. These seismic intensities in the fault zone are similar to the seismic intensities at many localities at distances up to 30 km from the fault.

2. On the San Francisco peninsula, the earthquake shaking damages indicate a minimum seismic intensity of RF VIII at most of the localities in the hills, which is much greater than the intensity ratings (RF V, VI, VII and VIII) shown on the Lawson maps.

Reports

Nason, Robert, 1978, Reexamination of the intensity maps of the April 1906 California earthquake: Earthquake Notes (Seismological Society of America), v. 49, no. 4, p. 14-15.

Semi-Annual Technical Report Summary

August 21, 1979

Computer-Based Earthquake Mapping

San Francisco Bay Area

Contract No. 14-08-0001-17751

Donald A. Olmstead
Jeanne B. Perkins

Association of Bay Area Governments
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Project Components

1. Several data files to be used that have not been available in ABAG's computer-based geographic data system are being developed, either by digitizing maps or by obtaining existing machine-readable data sets.

2. A series of earthquake hazard map files are being produced for the San Francisco Bay Area by combining the data files developed in the first task in various ways. The possible effects of earthquakes in the region as predicted by these files will be assessed.

3. Much effort is being made to ensure that this information is effectively communicated to city and county staff.

Research Progress

1. File Development

   o A geologic map of San Mateo County is being digitized.

   o The existing computer file of faults zoned by the State Geologist as part of the Alquist-Priolo Special Studies Zones Act is being expanded to include recent work on other active faults in the Bay Area.

   o Work will begin by the end of August on digitizing a map of flatland materials for the region.

   o A digital elevation model file of San Mateo County (including elevation and slope) is being obtained from the U.S. Geological Survey Topographic Division.

- o Dam inundation maps have been collected. The maps have all been redrafted on 7-1/2' quadrangle sheets because of the need to keep track of the dams which would inundate each area, as well as the areas which would be inundated.

- o A tsunami inundation map has been digitized and a computer file completed.

- o Some land-use information has been digitized for northern San Mateo County. This information will be digitized for the entire County for use in assessing the impact of earthquake hazards.

2. Reworking of Data Files

It is the intent of ABAG staff to develop a series of working papers to serve as documentation of the data and assumptions used to recombine the files into maps showing various earthquake hazards and risk. Three of the ten working papers to be written are now completed. They discuss:

- o faults and ground shaking intensity
- o tsunami inundation areas
- o dam inundation areas

The maps that will be produced by combining the files developed in the first task will show:

- o maximum intensity of earthquake ground shaking for the Bay Area

- o risk of damage from earthquake ground shaking for at least two types of buildings for the Bay Area

- o liquefaction potential for the Bay Area

- o relative slope stability for San Mateo County only

- o composite maximum earthquake intensity for San Mateo County

- o composite risk of damage from earthquakes for San Mateo County

The composite maps will be produced by combining the earlier maps of ground shaking, faults, slope stability, liquefaction, and dam and tsunami inundation.

3. Communication of the Information

Much effort is being made to ensure that this information is effectively disseminated. Key local staff are being involved in suggesting special projects and in designing the form of the final maps. For example, the City of Pacifica is most interested in having this information in a format suitable for an Environmental Impact Report. ABAG staff therefore are working on integrating this information into an automated environmental assessment system. The San Mateo Area Disaster Office is interested in an atlas of earthquake hazard maps for several cities at a scale of 1:24,000. The series of working papers being developed also will aid in receiving comments from local staff on the type of earthquake maps to be produced.

Data Processing, Golden

9940-02088

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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.

3. Develop a data processing center which utilizes the equipment available at Golden efficiently and in a cost-effective manner for Golden-based OES personnel.

4. Process ground motion data as requested by Golden-based investigators.

Results

1. A program for the reading of Geotech cassette tapes has been finished, to add the general cassette input S/W package.

2. A new analog digital converter has been installed on the PDP 11/40 and software is in development for input of analog data. A controller for control of the analog tape and strip chart recorder by the 11/40 is under development.

3. An effective, functioning computer committee has been set up under the chairmanship of Ray Buland to coordinate all hardware and software purchases, address user problems, determine operating procedures and policies, and plan long-range goals. The Golden Computer Center presently consists of the following systems: PDP 11/40, PDP 11/20, PDP 11/70, two PDP 11/03's, and the EAI hybrid system. The PDP 11/70 will run under the UNIX operating system and will be multi-user time-share system. The PDP 11/40 will run under RSX-11M and will be used primarily for data input and reduction. The PDP 11/20 will be used by the US Net event detection project. The PDP 11/03's are used as "front ends" for the 11/40 and 11/20. Peripherals will be assigned among the systems as most appropriate to their applications. Operational and programming personnel will work as a unit to support the center. Coordination of processing procedures, software development, and systems design for the three Golden-based OES branches will help avoid duplication of effort and allow for more efficient use of resources.

4. Processing of ground motion data was done for the L.A. Basin and Salt Lake projects. The L.A. Basin data has all been digitized and is stored on the Multics system.

Reports

King, K. W., Hays, W. W., Park, R. B., Jungblunt, W. J., 1979, An experiment to determine the attenuation characteristics of seismic waves in the Snake River Pain area, Idaho: Abstract, Seismological Society of America Meeting, Golden, Colorado, May 20-23, 1979.

Outer Continental Shelf Seismic Risk

9950-01917

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Investigations

1. Investigation of various methods of producing peak velocity attenuations having properties similar to the peak acceleration attenuations of Schnabel and Seed.

2. Preparation of probabilistic maximum velocity maps for
   (a) Alaska and Alaskan Outer Continental Shelf (OCS)
   (b) Southern Pacific Coast and OCS from Mexico to Cape Mendicino
   (c) Northern Pacific Coast and OCS from Cape Mendicino to Canadian border
   (d) Atlantic Coast and OCS

3. Modification of seismic risk computer program to run more efficiently and accurately.

Results

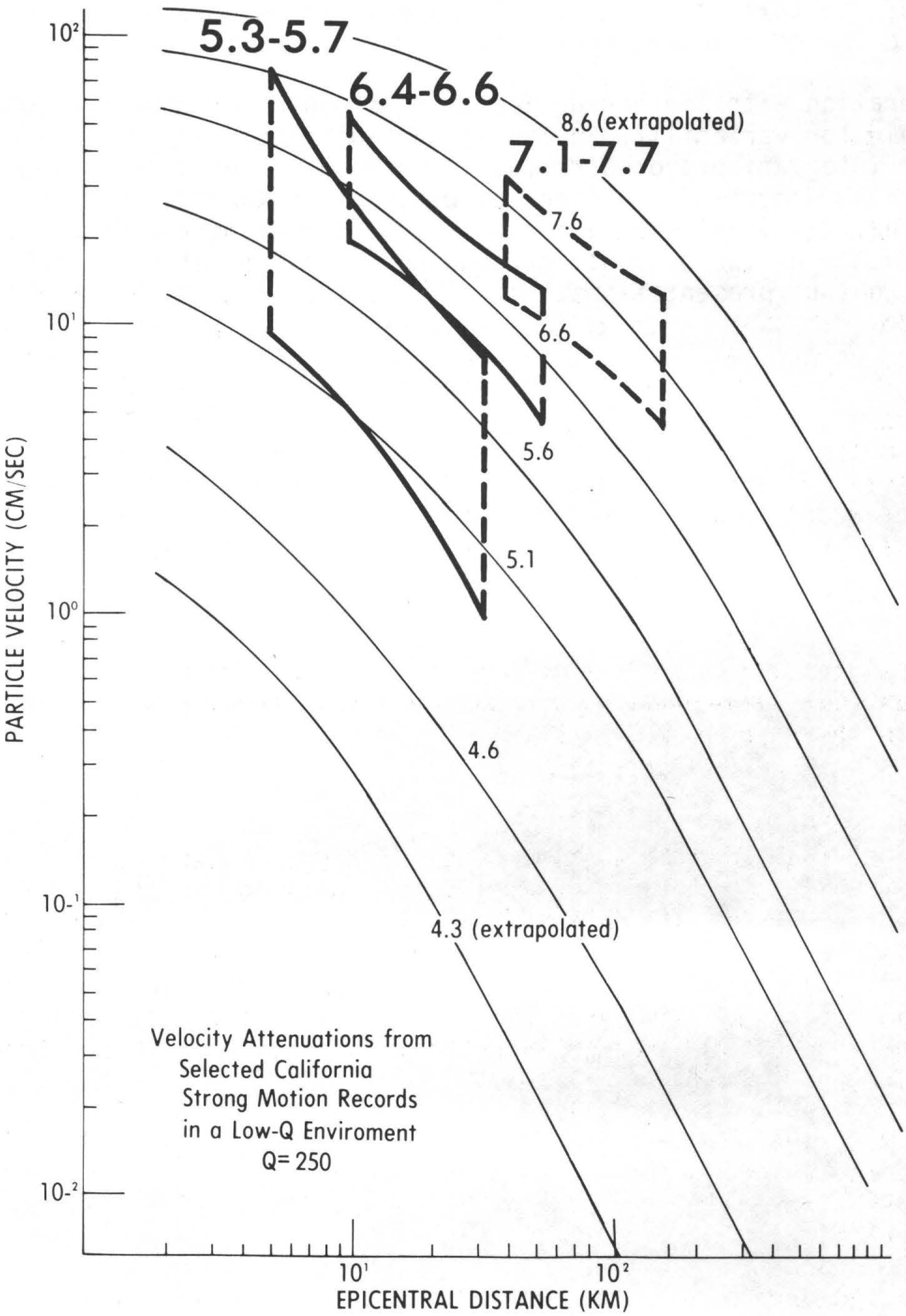
1. Harding and Harmsen modified a computer program to perform attenuation on strong motion peak velocity in a manner similar to that performed by Schnabel and Seed for body wave attenuation. That is, the velocity Fourier amplitude spectrum was adjusted for relative distance to faulting, taking into account finite source size for geometric attenuation and frequency-dependent attenuation for inelastic attenuation. The strong-motion records used were selected from those used by Schnabel and Seed. The distance-corrected velocity amplitude spectra were inverse-transformed and the new maximum velocities were determined from the resultant new time series. This calculation was performed at a number of standard distances out to 500 km. The resultant velocity attenuations for individual earthquake records were sampled by Perkins at the standard distances to give magnitude-dependent peak velocity curves for each standard distance. These curves were smoothed and extrapolated for higher and lower magnitudes and then sampled at standard magnitudes to produce distance-dependent attenuations for the standard magnitudes. Attenuation beyond 500 km was set to equal the general point-source attenuation calculated for larger distances. Curves for the western United States were determined by performing these calculations in a $Q = 250$ environment. For the eastern United States, these same earthquakes were placed in a $Q = 1200$ environment.

This procedure results in comparability between east and west attenuations for the same epicentral intensities and is roughly equivalent to the procedure used by Algermissen and Perkins for the U.S. hazard map of 1976 and for the present work on acceleration hazard in the OCS. However, the problem of determining magnitude and source properties of earthquakes in the eastern United States precludes broader application of these curves. Further work is being continued in another project, assuming now that surface wave attenuation is important for strong ground motion.

2. Probabilistic extreme velocity maps were produced for all four regions at a scale of 1:2,500,000, for return periods of 100, 500, and 2,500 years.

3. Drafts of the texts accompanying the acceleration hazard maps have been circulated to the contracting agencies, co-authors, and reviewers.

4. In cooperation with another project, the computer program has been modified again for variability in magnitude-fault-length relationship. A point-source integration procedure from McGuire has been incorporated into the seismic risk program. A general piece-by-piece examination and reprogramming has resulted in a factor of four increase in speed, with an additional factor of two possible through some less stringent, though just as accurate, output presentations.



Peak velocity attenuation of Perkins, Harmsen, and Harding compared to envelopes from Boore, Joyner, and others (1979).

Seismic Zonation Studies in Los Angeles Basin

9940-01730

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Investigations

Nineteen NTS nuclear explosions have been utilized to obtain 157 3-component records in the Los Angeles Basin region. These data have been processed to obtain digital seismograms of ground velocity, Fourier spectra, PSRV spectra, and alluvium-to-rock spectral ratios. The latter quantity approximates the site transfer function. The mean site transfer function has been computed over several period bands in the period range of the recorded signal, 0.1 to 10.0 seconds. These data are being studied in relation to the geological conditions and properties of near-surface soils underlying the site. Site transfer functions obtained from the nuclear data are also being compared with site transfer functions obtained from the San Fernando earthquake at the 29 sites where both sources have been recorded. An open-file report presenting all of the data used in this study is being completed.

Results

The principal results obtained in this study to date have been summarized in the previous four semi-annual technical reports. These results are presented in detail in the reports listed below.

Reports

Rogers, A. M., and Hays, W. W., 1978, Ground response studies in three western United States cities: Sixth Symposium on Earthquake Engineering, Proceedings, Univ. of Roorkee, Roorkee, India, VI, p. 21-25.

Rogers, A. M., and Hays, W. W., 1978, Preliminary evaluations of site transfer functions developed from earthquakes and nuclear explosions: Second International Conference on Microzonation, Proceedings, San Francisco, CA, v. 2, p. 753-764.

Rogers, A. M., Tinsley, J. C., Hays, W. W., and King, K. W., 1979, Evaluation of the relationship between near-surface geologic units and ground response in the vicinity of Long Beach, Calif.: Seismological Society of America, v. 69, p. 1603—1622.

Hays, W. W., Rogers, A. M., King, K. W., 1979, Empirical data about local ground response: Proceedings of the 2nd U.S. National Conference on Earthquake Engineering, Stanford Univ., p. 223-232.

Seismic Response Mapping of St. Louis County (Pilot Study)

Grant No. 14-08-0001-G-518

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It is the objective of this research to provide the data necessary to define the magnitude of seismic risk and the nature of seismically associated geological hazards in a selected portion of St. Louis County (Creve Coeur), and to present these data in a form useful to those public and private officials involved in land-use planning.

The research is being carried out in two phases. The objectives of Phase I are to identify the local geologic conditions; soil and bedrock distribution and stratigraphy, the local tectonic system and its relationship with the regional tectonic framework, and the response of these materials to earthquake induced rock motions.

Field Exploration

The major objectives of this stage have been successfully completed. High quality soil specimens have been obtained for standard and dynamic laboratory testing and the local geologic conditions have been investigated. The soil stratigraphy, depth to bedrock, ground water elevation and relative density of cohesionless deposits were determined.

The field boring program was conducted from the 12th through the 27th of June, 1978. The four (4) test borings were drilled by the Layne-Western Company of St. Louis.

Determination of Earthquake Induced Ground Motions

Estimates of bedrock motions at Creve Coeur, from two design earthquakes, have been determined in terms of the peak horizontal accelerations, peak horizontal velocities, the frequency content of the ground motion and bracketed durations. These values have been used to select and modify design earthquake accelerograms. From these studies, two design earthquakes have been selected as representative of the maximum bedrock motion can be expected at Creve Coeur. The design earthquakes consist of a near field, high frequency Ozark Uplift earthquake and a far field, low frequency New Madrid earthquake. The peak horizontal acceleration, peak horizontal velocity, predominant period, and bracketed duration for both design earthquakes are shown in Table 1. Existing acceleration time histories can be modified to match these ground motion parameters to produce the design earthquake accelerograms.

TABLE 1

Seismic Source Zone	Peak Horizontal Acceleration Percent g	Peak Horizontal Velocity cm/sec	Predominant Period (sec)	Bracketed Duration (sec)
Near Field Earthquake Ozark Uplift	46	140	0.30	> 21
Far Field Earthquake New Madrid Region A	25	188	0.82	> 10

Laboratory Activities

The principle activities in the laboratory have been the development of instrumentation for the cyclic triaxial testing program, the determination of appropriate dynamic testing parameters and the completion of laboratory classification tests. A computer controlled data acquisition system has been developed to facilitate test operation and data analysis.

The cyclic triaxial testing program will be divided into two studies. The first will be the determination of shear strain (γ) dependent dynamic properties of shear modulus (G) and damping (D). These tests will be cyclic strain controlled consolidated-undrained tests with pore pressures measured.

The second laboratory study will be to determine the liquefaction properties of the soils. These tests will be cyclic stress-controlled consolidated-undrained triaxial tests. The variables monitored will be stress, displacement, pore pressure and number of load cycles. The results will be: 1) the number of cycles to 100 percent pore pressure rate and the number of cycles versus strain level. Currently, testing is being delayed until the arrival of additional test equipment necessary to complete the program.

Mathematical Modeling

In order to model the study area, it was necessary to determine representative geologic profiles for the region. These profiles were chosen based on their geologic occurrence and their significance on ground motion response. Six profiles were selected as typical of the region. These profiles, and the soil parameters developed from the laboratory study, will be used in the SHAKE II computer model to determine ground response to the six earthquake motions postulated as bedrock input motion.

The objectives of Phase II of the proposed research is to evaluate the level of severity of potential geological hazards associated with seismic activity. Zoning maps based on developed criteria will be prepared. In order to accomplish the goals of Phase II, the following principles and techniques are being utilized: Field Exploration and Laboratory Investigation, Analysis.

Field Exploration

The field exploration phase has been completed as described previously.

Laboratory Investigation

This stage is currently underway as described previously. Completion is projected by March 1, 1980 due to equipment delivery delays.

Analysis

Currently, geologic microzones have been delineated as described previously. These zones will then be modeled in the computer and their responses determined. Upon completion of the mathematical modeling stage of the investigation, the study regions will be delineated into hazard microzones. These hazard microzones will be defined by engineering response parameters that have yet to be defined. Once these zones are selected, computer data base maps will be produced on the final stage of the research.

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Analysis of Strong Motion Data and the Effects of Earthquake Source Parameters on Ground Motion in California

Summary of Semi-Annual Technical Report, 1 July - 31 December, 1978
Contract No. 14-08-0001-16756

Principal Investigator: M. Nafi Toksöz

Strong motion data were studied to investigate the effects of the source, medium and site on ground motion observations from several earthquakes. The most extensive data are from the 1971 San Fernando earthquake. The analysis of Hanks (1975) based on displacement records were extended to the velocities and accelerations. The San Fernando data shows an azimuthal variation due on the source rupture process. Records from stations to the north and east of the fault, on the up-thrust block, are of shorter duration and less complexity than those to the south and west, on the down-thrust block. The decay with distance for stations to the southeast is much less rapid than the decay for stations to the northwest. The records from some stations in the San Fernando Valley show clear surface wave phases apparently associated with the fault rupture breaking the surface. Analysis of the strong motion data from the 1968 Borrego Mountain earthquake shows possible effects of the source mechanism, but the station distribution is not sufficient to clearly establish this dependence. The data from the Puget Sound earthquakes of 1949 and 1965 shows strong effects of the local geology on the recorded ground motion. These local effects are important in the estimation of the seismic hazard due to strong ground shaking.

Geotechnical Studies

9940-02089

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Investigations

In-situ geophysical measurements especially shear wave velocity and amplitude studies.

Results

1. The bore hole near the old Chalome #2 strong motion recorder site was logged for shear and P wave velocities on Joyner's 01168 project.

2. The evaluation of the Sprengnether DR-100 digital recorders and accelerometers continues.

3. Some assistance was given to the development of the microprocessor based recorder prototype under Borcherdt's 02409 project.

DIFFRACTION OF WAVES BY THREE-DIMENSIONAL SURFACE TOPOGRAPHIES AND SUBSURFACE IRREGULARIITES

U.S.G.S. Contract No. 14-08-0001-17765

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Goal: The objective of this research project consists of three major parts: (1) the analysis of experimental data obtained in the Pasadena Basin during a series of force vibration tests on the Millikan Library at Caltech, (2) a theoretical study on the effects of housing on the recorded accelerograms; several realistic structural and wave propagation models are to be used, and (3) the derivation of better and more efficient numerical methods for the analysis of wave scattering in irregular soil layers.

Investigations and Results:

1) More than 500 records obtained in an area of approximately 50 square kilometers during forced excitation of a building have been recorded on analog magnetic tapes. The frequency content of the data is monochromatic having the frequencies of the building's fundamental modes. The signals are strong for stations located near the source, but for locations far away from the building, environmental noises have comparable amplitude to the signals. In the first stage of data analysis, the amplitudes of ground motion were estimated from a strip chart recorder. In the second stage which is currently being performed, the data will be analyzed through an A/D converter and a digital computer. Theoretical modeling of the experimental data will follow the more accurate data analysis in the second stage. Presently, a preliminary theoretical model with parallel layers has been compared to the data from stage one; both the radiation patterns and the amplitude ratios have been compared favorably.

2) The effects of housing on the recorded free field accelerograms have been analyzed by a theoretical soil-structure interaction model. Several sets of realistic geological and building parameters have been used for this analysis, but the observed effects are surprisingly small for most conventional buildings (nuclear power plants excepted). Excluding cases with extremely soft soil, the interaction effects on the recorded accelerogram may go undetected by eye; the Fourier spectrum of the time history, however, does show filtering as well as amplifying effects at the resonance frequencies of the building.

3) In seismology, an alluvial layer is generally much longer in its horizontal dimension than its depth; therefore, the emphasis of wave diffraction studies have been shifted to the analysis of thin irregular layers. Currently, the research is focused on a numerical method which combines the versatility of finite elements for geometric modeling and the efficienty of integral equations for wave propagation studies. An extra effort is made to reduce the cost of Green's functions calculations.

PUBLICATION:

Wong, H.L. (1979). The Diffraction of P, SV and Rayleigh Waves by Surface Topographies, Report No. 79-05, Department of Civil Engineering, University of Southern California, Los Angeles.

Ground Motion Prediction and Eastern U.S. Earthquake Monitoring

Contract No. 17739

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Investigations

1. Develop a method of using small earthquakes to predict the near source ground motion of a large earthquake.
2. The establishment of stations in northern and western New York.

Results

1. The theoretical basis of an "Impulse Response method" of ground motion prediction has been developed. The ground motion caused by a large earthquake can be viewed as a convolution of the impulse responses with an appropriate source time-space function. The recording of small earthquakes on force-balance accelerometers has proved to be feasible. In a field recording program after the occurrence of the August 6, 1979 Gilroy earthquake (magnitude ~5.9) we have found that all the magnitude 2 or above events (USGS magnitude) within a distance of 25km have been recorded (no M>2 events occurred farther than 25km during the period we monitored).

2. One station has been established in the Long Sault Dam near Massena, N.Y. Other sites are under negotiation. When the new instruments we purchased on this contract function properly more stations will be established in western N.Y.

STUDY OF LIQUEFACTION IN NOVEMBER 23, 1977 EARTHQUAKE SAN JUAN PROVINCE, ARGENTINA

Contract No. 17649

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Liquefaction produced in Valle de Tulum by the 7.4 Richter Magnitude November 23, 1977 Caucete earthquake was largely limited to the areas North and East of the Rio San Juan. A large portion of the area West of the river consists of an alluvial fan, the coarse sediments of which are not susceptible to liquefaction. Thus, the City of San Juan, which is situated on the fan, did not experience liquefaction-related damage. In contrast, the urban and agricultural areas North and East of the city were extensively damaged by widespread liquefaction.

The character and the mechanical properties, the distribution of soils, surface sediments, ground water, surface water and geomorphic features were studied in an effort to evaluate the influence of various geologic factors on the observed spatial distribution of liquefaction.

The investigations were initiated with a two and one-half long field geologic reconnaissance intended to study the character and distribution of soils, ground and surface water, geomorphic and geologic features. After this, the subsurface exploratory program was initiated. Six borings were advanced to a maximum depth of 20 meters (65.6 ft) below ground surface. Shelby tubes, Dennison samplers, and standard split-spoon barrels were utilized in the extraction of soil samples, and in the determination of the in-situ density. A total of 16 shelby tubes, 2 Dennison samples and 102 standard penetrometer split-spoon samples were obtained.

A laboratory testing program was also carried out with the purpose of obtaining the classification of the subsurface materials, and the static and dynamic properties of the soil types more relevant to this investigation. The testing program included strength tests, cyclic triaxial tests, plasticity and grain size distribution, maximum and minimum density tests.

With the above data, earthquake engineering studies were carried out to relate geology, soil properties, and ground motions to the observed liquefaction, and to examine the applicability of current methods of liquefaction potential evaluation to the Caucete experience.

Conclusions based on the field and laboratory investigations and data analysis may be summarized as follows:

Although the soils and surface sediments on the flood plain in Valle de Tulum reflect temporal changes in the location and character of the main channel of the Rio San Juan, the locations that experienced liquefaction show no apparent relationship to the distribution of major soil types mapped in the flood plain by INTA.

Small paleochannels identified on the Rio San Juan floodplain were produced during flood events; many of these channels, which have no topographic expression and some of which are buried, were preferred sites of liquefaction with surface manifestation, such as boils, ground cracking, etc., during the November 1977 earthquake. Although surface manifestations of liquefaction were seen in many of the paleochannels East of the river, no evidence was found for these manifestations of liquefaction associated with apparently similar channels west of the river. Liquefaction, however, was not limited to the location of the paleochannels, nor all of the paleochannels showed liquefaction. The topography of the floodplain and the presence of dune sands on the floodplain west of the river suggest that that side of the floodplain is less subject to flooding than is the area east of the river. Thus, it appears that the paleochannels west of Rio San Juan are older than many of those east of the river.

Extensive irrigation in the central portion of the Valle de Tulum has produced a body of perched ground water with a water table generally within one to six meters of the surface. The loose fine-grained floodplain sediments, saturated by the perched ground water, were highly susceptible to liquefaction and experienced that phenomena during the November 23, 1977 Caucete earthquake.

It appears that the loose fine grained sediments in some of the younger paleochannels are overlain by layers of a stiff fissured and dessicated clay that present a barrier to the dissipation of the excess pore water pressure generated within the loose sands in the liquefaction process. As a consequence, enough pore water pressures were built-up below the clay layers until they were sufficiently high to open-up the fissures accross the clay layers, and burst to the surface carrying abundant water and sand.

Some sediments in some of the older channels may have also liquefied during the earthquake, but the excess pore water pressure built-up during the process dissipated through the overlying sands and silts, as at these locations there were no clay layers to inhibit the fast dissipation and drainage of the liquefying sands.

Curvilinear surface cracks were produced along the margins of many of the paleochannels; where curvilinear cracks occurred, the channel area usually subsided relative to the surrounding area. Linear surface cracks associated with liquefaction did not experience vertical offset and were located either in the central portions of paleochannels or in areas where no evidence for the presence of a paleochannel was found.

It appears that the standard sampling procedures used in this study are not adequate to provide true "undisturbed" samples of sands. Medium dense to dense sands tend to densify in the process, while dense to very dense sands tend to dialate. In eiher case, field characteristics of the deposit which have great importance in its liquefaction vulnerability were lost.

The empirical method to evaluate soil liquefaction potential provides a coherent picture of the liquefaction observed in the study area during the Caucete earthquake (1977). The method indicates that liquefaction during that earthquake (Magnitude M_L = 7.4), occurred at stress ratios in the field equal to 0.15 or higher, in sand deposit with an N_1 value of 15 or lower.

The application of the analytical method of liquefaction evaluation to practical cases is complicated by the difficulties in interpreting the laboratory test data. Since disturbance of samples should be expected, during sampling and handling, judgement must be applied to laboratory test results before they can be introduced to the analysis.

Six boreholes were completed during this investigation (2 more than originally proposed). The horizontal distance between boreholes is such that it is not possible to determine the two-dimensional distribution of the soil layers in the study areas, nor to prepare subsurface cross-sections.

To expand on the study of the soil layering, the continuity of near surface clayey soil layers, and the importance that those layers had on the distribution of liquefaction, it would be necessary to prepare and study subsurface cross sections at selected locations, two of which could be at the Justo P. Castro Site, and at the San Martin Winery. Four to five additional borings at each location would appear to be necessary to define the subsurface two-dimensional distribution of the soils in these areas.

PROJECT TITLE: "Development of Techniques for Evaluating Seismic Hazards Associated with Existing Creeping Landslides and Old Dams"

RESEARCH GRANT NUMBER: 14-08-0001- 17761

PRINCIPAL INVESTIGATOR: Richard E. Goodman

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SIX MONTH TECHNICAL REPORT

The studies under this contract include measurements of creep rates in suspected and actual existing slides, and development of methods to locate, describe, and assess the importance of fractures in the foundations of existing dams. A comprehensive report of activities of the first year was presented as the Final Technical Report of the first year's contract. Progress during the first half of the second year is summarized below.

Creep Studies:

In the past six months, field studies of creeping slopes have not been pursued. The LVDT probes had rusted inside due to extensive use outdoors in snow and rain in Colorado and California. In January 1979 they were returned to Serata Geomechanics, the supplier, for servicing and replacement. A rather dry winter with scattered instead of intense storm activity resulted in reduced landslide activity at proposed measurement sites. Current plans are to await the 1979-80 wet season before resuming field measurements. Sites selected for study, in addition to those monitored previously, are the Week's Creek and Congress Springs landslides, in the Bay Area. To permit studies through the coming rainy season, a no-cost extension will be requested.

Fracture studies:

A device to record fractures on the walls of boreholes, and to permit deformability measurement at the same time, has been fabricated and is being calibrated in the laboratory. The device is an impression packer with a wax film impression material. Two bearing plates, coated with a soft rubber back-up material and wax film are driven out against the borehole wall by the expansion of a central rubber packer. For dilatometry, the impression plates are then removed and the device is inserted into the hole as a rubber packer. The pressure we can obtain without rupture of the packer is considerably greater than that permitted by the prototype impression packer constructed by Imperial College, but it is far too low for work in very hard rock. Therefore, we have also placed an order with Lynes Company for a novel high pressure packer. We are constructing a thin-walled cylinder of steel for calibration of the dilatometers, so that the expansion can be monitored by metering the flow of water into the packer during the test. The calibration device is equipped with strain gages on the outer surface; the intention is to bring it to the field for calibration routinely in every measurement program.

Earthquake-Induced Landslides

9550-01452
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Investigations

1. Performed testing and checkout of portable strong motion seismometer to be used for recording ground motion directly responsible for triggering landslides (especially rock falls).

2. Completed preliminary evaluation of seismic slope stability for San mateo County, California.

3. Conducted reconnaissance of ground failure from the April 15, 1979, M=7.0, earthquake in Yugoslavia.

Results

1. Recently acquired portable seismometers have been tested and appear to be well-suited for the planned investigations concerning measurement of landslide-triggering ground motion and the amplification of ground motion by topography and its affects on landslide generation. As yet no real data have been gathered from either aftershocks or blasts.

2. An experimental map depicting seismic-induced slope stability has been prepared for San Mateo County, California. This map is similar to a previous map prepared for the La Honda 7 1/2' quadrangle in San Mateo County (see previous semi-annual report). This map is based on criteria consisting of slope, strengths of existing geologic materials, and a dynamic model of shaking effects on a spectrum of geologic materials. These criteria divide the mapped area into four categories: Category 1, areas of lowest susceptibility, have critical accelerations of over 30 percent g. Intermediate categories, 2 and 3, contain areas of geologic units with critical accelerations of between 10 and 30 percent g. The least seismically stable areas, category 4, contain units with critical accelerations of over 30 percent g. Approximately 35 percent of the area in San Mateo County falls into category 4, about 40 percent in category 1, and the remaining area into the two intermediate categories. Further revision of the mapping method will be required to accurately estimate and depict seismic-induced landslide susceptibility as more data are gathered and as adjustments in criteria are made.

3. The M_s=7.0 April 15, 1979, Yugoslavian earthquake caused liquefaction-induced ground failure along 100 km of the Yugoslavian coast from the Bay of Kotor to the Albanian border. Lateral spreading and subsidence extensively damaged the shipyard at Bijela, two hotels and the dock in Kotor, and seven houses in Tivat. Fine and medium sand from deltaic and alluvial deposits liquified and vented to the surface in sand boils and along surface

fissures. There were no deaths or casualties from ground failures because the earthquake occurred on Sunday prior to the tourist season, when both the shipyard and hotels were empty.

An estimated 1,000 landslides occurred in a 25-km-wide mountainous belt of limestone, flysch, and siliceous carbonate rock from Ulcinj to Kotor. Near Budva rockslides and rock falls in limestone blocked the highway for more than 1 km, and an incipient rockslide fractured the highway tunnel. Block slides and slumps that moved less than 1 m in siliceous carbonate rock and colluvium damaged the highway in several places between Petrovac and Virpazar. The highway between Sutomore and Bar was cracked by renewed movement of several preexisting landslides in fill. In the village of Kaliman, eight houses were destroyed by a slump/earthflow in clay-rich flysch deposits. This landslide of more than 2.5 million m^3 moved more than 100 m during several days following the earthquake.

Owing to intensive development along the Yugoslavian coast, liquefaction-induced ground failures were the most significant ground failures caused by the earthquake. If the earthquake had occurred on a workday or during the tourist season, many lives could have been lost.

Reports

Harp, E. L., Keefer, D. K., and Wilson, R. C., Landslides from the August 13, 1978, Santa Barbara earthquake: California Geology (in press).

Wieczorek, G. F., Wilson, R. C., and Harp, E. L., 1979, An experimental seismic slope stability map of the La Honda 7.5' quadrangle, San Mateo County, California [abs.]: Geological Society of America Programs with Abstracts, 1979 Annual Meeting.

Wieczorek, G. F., and Ivanovic, S., 1979, Ground failures during the April 15, 1979, Yugoslavian earthquake [abs.], in International Geological Congress, 25th, Paris, France, Programs with Abstracts: (in press).

Ground Failures Caused by Historic Earthquakes

9550-02161
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Investigations

1. We are assembling and abstracting reports on historic earthquakes. From reports that have been abstracted for 24 earthquakes, we are extracting data on the extend and types of ground failures (slope failures, fissuring, settlements, liquefaction, etc.) and on the geologic environments in which these failures occur. A major product of our research will be a synthesis of this information. The quality of data concerning ground failures can be divided into three categories: (1) high quality reports on ground failures, (2) moderate quality reports where ground-failure information is available but is diffuse and can be extracted only with some effort, and (3) reports where ground failures are mentioned but where information on geologic setting and failure type can only be extracted with considerable effort by tracking down general geologic reports on the area, unpublished information, or information stored in archives. We are currently concentrating our efforts on reports in the second category, since information in the first category can be incorporated into the final synthesis with relative ease.

2. We are continuing to perform post-earthquake field investigations to supplement the literature review. Following the Coyote Lake, California, earthquake of August 6, 1979, we conducted reconnaissance studies in the epicentral region to determine the types and distribution of ground failures.

Results

1. Data from 20 historic earthquakes have been analyzed to determine types, distribution, and geologic settings of earthquake-induced landslides. In order of decreasing abundance, the most frequently reported types of earthquake-induced landslides are: (1) rock falls and slides of rock fragments from steep slopes, (2) shallow debris slides from steep slopes, (3) liquefaction-induced lateral spreads from bluffs, riverbanks, deltas, lakeshores, seacoasts, and artificial fills, (4) soil slumps and block slides from moderate to steep slopes, and (5) rock slumps and block slides from moderate to steep slopes. Dormant slumps and block slides are rarely reactivated by earthquakes.

Large earthquake-induced rock and soil avalanches and subaqueous landslides occur less frequently than the five types of landslides discussed above, but they are particularly hazardous to human life and property. Subaqueous landslides commonly involve the distal margins of deltas where many port facilities are sited. Rock avalanches originate on steep, high slopes in weak rocks. Soil avalanches occur in some weakly cemented materials, including loess and volcanic pumice, that form steep, stable slopes under nonseismic conditions.

The size of the region affected by landslides in an earthquake is strongly dependent on the earthquake's magnitude as well as on focal depth, ground-motion characteristics, and topographic and geologic conditions. In many earthquakes, landslides are abundant in areas with shaking intensities as low as Modified Mercalli Intensity VII, and some landslides occur where intensities are even lower.

2. The most abundant ground failures observed during our field studies in the epicentral region of the August 6, 1979, Coyote Lake, California, earthquake were rock falls with volumes of less than 10 m^3, which occurred on steep roadcuts, and rotational slumps in road pavements and shoulders, which moved a few millimeters as a result of the earthquake. Ground cracks possibly caused by fault movement were also noted at one site. Rock falls with volumes of more than 1 m^3 and slumps were observed only within 6 km of the zone containing the surface traces of the Calaveras Fault. The highest concentrations of ground failures were observed on the Gilroy Hot Springs Road, within 6 km of the earthquake's epicenter, and on the slopes above Anderson Lake, within 10 km of the epicenter.

Reports

Keefer, D. K., Wieczorek, G. F., Harp, E. L., and Tuel, D. H., 1979, Preliminary assessment of seismically induced landslide susceptibility, in Brabb, E. E., ed., Progress on seismic zonation in the San Francisco Bay region: U.S. Geological Survey Circular 807, p. 49-60.

Keefer, D. K., 1979, Landslides in historic earthquakes [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 454-455. (1979 Annual Meeting.)

Keefer, D. K., 1979, Review of "Dynamic methods in soil and rock mechanics--Proceedings of NATO advanced study institute and international symposium": Geology, v. 7, no. 10, p. 474.

Harp, E. L., Keefer, D. K., and Wilson, R. C., 1979, Landslides from the August 13, 1978, Santa Barbara earthquake: California Geology (in review).

Evaluation of the Cone Penetrometer for Liquefaction Hazard Assessment

14-08-0001-17790

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The program is directed at evaluating the potential of the Cone Penetrometer for use in assessment of liquefaction hazard on a regional or site specific basis. Current capabilities for quantitative assessment of liquefaction hazard are limited to simplified methods based upon Standard Penetration Tests or more elaborate methods involving sampling, laboratory cyclic testing and dynamic analyses. Because of high cost, the more elaborate methods are not suitable for regional microzonation efforts. Likewise, the simplified methods require a field boring which results in unacceptably high costs when planned for use on a regional basis. Additionally, the Standard Penetration Test gives discontinuous data over the depth of soil profile, and produces results very sensitive to slight changes in procedure.

The Cone Penetrometer Test is rapid (2 cm/sec), easily standardized, and does not require a boring. However, simplified methods of liquefaction hazard assessment are based upon observations of liquefaction at sites where Standard Penetration Tests had previously been performed. As data of this type does not exist for Cone Penetrometer Test measurements, it is first necessary to relate CPT data to SPT data and hence to liquefaction hazard.

The investigations underway in this program (to be completed in 1980) are of the influence of geologic origin, age, and physical properties of cohesionless soils upon the CPT-SPT correlations. If it is shown, based upon field investigations at several different sites, that the properties of the soils influence both CPT and SPT data in a predictable manner, then the CPT method will provide a valuable approach for liquefaction hazard assessment.

Earthquake-Induced Liquefaction and Subsidence of Granular Media

14-08-0001-17770

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Investigations

The behavior of dry or saturated granular materials under cyclic shearing has been investigated theoretically, in an effort to identify the major micromechanical factors which are essential for the description of the consequent densification of drained soils, and liquefaction of undrained saturated soils. Comparison has been made with published experimental results. Additional experimental results are being obtained, in order to verify the validity of the theoretical assumptions, and to quantify the material parameters.

Results

1. When subjected to cyclic shearing, loose dry sand densifies, and undrained saturated sand may liquefy. These phenomena have to be described in terms of the complete loading history. An effective procedure for such a description would be to utilize the concept of "internal state variable." In this study, relative void ratio (i.e. the difference in void ratio and its minimum value) and pore water pressure are used as internal variables for densification and liquefaction phenomena, respectively. With the aid of these quantities, a unified theory for densification and liquefaction of a macroscopically homogeneous sample of isotropic cohesionless sand is proposed, and the corresponding stress-strain amplitude relation is then developed. The basic observation underlying the theory is that these phenomena involve a rearrangement of grains at microlevel, that requires expenditure of a certain amount of energy which increases as the void ratio approaches its minimum value, and decreases as the excess pore water pressure increases. Based on this energy consideration the evolutionary equations are developed in such a manner that when combined with stress-strain relation, they yield expressions relating stress (or strain) amplitude to the number of cycles and other relevant parameters. On the basis of rather rough estimates these relations are then rendered explicit and the results are applied to predict some of the existing experimental data.

2. When a sample of granular cohesionless material is horizontally sheared under vertical pressure, it is experimentally observed that:

   (a) There is always an initial densification (decrease in void volume), the magnitude of which decreases as the initial void ratio approaches its minimum value;

(b) if the sample is dense (i.e. its initial void ratio is close to the corresponding minimum value), then the initial densification will be followed by dilatancy (increase in void volume) which continues until a critical void ratio is attained asymptotically;

(c) if at a certain stage during the course of dilatancy, discussed in item (b) above, the shearing is reversed, and the shear strain is gradually decreased to its initial zero value (completing half of a strain cycle), then there is always a net amount of densification, this amount decreasing as the initial void ratio approaches its minimum value;

(d) if the sample is loose (i.e. the initial void ratio is larger than the critical value), then the sample densifies continuously until the critical void ratio is reached asymptotically.

A statistical theory for the two-dimensional flow of cohesionless granular materials has been developed, which provides a mechanical description of all of the above-mentioned phenomena in a simple and convincing manner. Since it relates to the behavior of individual grains relative to each other, the theory does not involve many empirical constants. The resulting dilatancy equation, however, accords well with observed experimental data.

<u>Reports</u>

Nemat-Nasser, S., and Shokooh, A., 1979, A framework for prediction of densification and liquefaction of sand in cyclic shearing: Ingenieur-Archiv, in press.

Nemat-Nasser, S., 1979, On behavior of granular materials in simple shear: Earthquake Research and Engineering Laboratory, Technical Report No. 79-6-19, Dept. of Civil Engineering, Northwestern University, June 1979; submitted to Soils and Foundations.

Nemat-Nasser, S., 1979, Finite deformation plasticity and plastic instability: (Invited General Lecture) Transactions of Twenty-fifth Conference of Army Mathematicians, Baltimore, MD, June 6-8, 1979, to appear.

Ground Failure Related to the New Madrid Earthquake
9550-02160

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Investigations

1. Completed determination of areal extent and percentage of land surface covered with sand blows by using airphotos on file at the National Archives, Washington, D.C.

2. Conducted field engineering tests (Standard Penetration Tests) to determine areal extent of materials susceptible to producing sand blows.

3. Trenched suspected sand blows in Obion River valley, Tennessee, for verification of blows.

4. Made six traverses across sand blow region between Sikestone, Missouri and Memphis, Tennessee, to determine character and thickness of extruded sand in sand blows.

Results

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

2. Large regions in the Mississippi River alluvium adjacent to Sikeston's Ridge are only weakly susceptible to sand-blow development because the sands are either coarse or have high relative densities (as reflected by high Standard Penetration Test (SPT) blow counts).

3. The alluvial region west of Crowley's Ridge in northeastern Arkansas shows little evidence of sand-blow activity as a result of the 1811-12 earthquakes. Thus it is most unlikely that the epicenters for the 1811-12 earthquakes were west of Crowley's Ridge.

Reports

None.

Interactions Between Ground Motion and Ground Failure

9550-01628

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Investigations

1. Conducted reconnaissance survey of ground failures induced by the August 6, 1979, Coyote Lake, California earthquake.

2. Performed dynamic analysis of a landslide triggered by the Coyote Lake earthquake to test the physical validity of existing seismic slope stability analyses.

3. Continued development of mapping criteria and preparation of seismic slope stability map of San Mateo County, California.

Results

1. A magnitude 5.9 earthquake occurred on the Calaveras Fault near Coyote Lake, Santa Clara County, California, at 10.05 a.m. PST on August 6, 1979. That afternoon, Ray Wilson, Dave Keefer, and Nancy Tannaci conducted a reconnaissance of seismic-induced ground failures in the southern Santa Clara valley from Morgan Hill to Hollister. We observed relatively few landslides and no evidence of liquefaction. A fissure was observed across Shore Road near Tesquiquita Slough, at approximately the position of the mapped trace of the Calaveras Fault. This fissure may represent fault rupture but no measurable horizontal offset occurred. Minor (<5 m^3) rock falls were noted along State Highway 152 west of Pacheco Pass and along the Ruby Canyon and Gilroy Hot Springs roads east of Gilroy. A small (~ 10 m^3) rock fall occurred in a roadcut near the trace of the Calaveras Fault on the south shore of Lake Anderson. Across the road, a turnout was broken up by a number of fissures, indicating an incipient slope failure. A prominent fissure across the road on the north shore of Lake Anderson was investigated and initially thought to represent fault rupture. Further investigation revealed that this fissure was the scarp of an incipient slope failure triggered by this earthquake (see item 2 below). In summary, the Coyote Lake earthquake, although the largest earthquake in the San Francisco Bay region in 20 years, triggered very few ground failures. A partial explanation may be that the dry summer conditions lowered the meteoric water table below potential slide planes. A similar relative paucity of slope failures was noted in our investigation of the Oroville, California earthquake in August 1975.

2. The fissure across the Lake Anderson road (see item 1 above) appears to result from reactivation of a preexisting landslide by the Coyote Lake earthquake. The fissure appeared to be very fresh on the day of the earthquake and extended for over 20 m obliquely across the asphalt roadway and onto the dirt shoulders on both sides. The fissure was opened 12-18 mm, with 5-10 mm of vertical displacement (down to the south). The fissure appears to represent the scarp of an older slump landslide in weathered shales of the

Cretaceous Berryessa Formation. The displacements measured across the fissure indicate a seismic-induced displacement of the landslide mass of approximately 20 mm.

Coincidently, accelerographs of the Coyote Lake earthquake were recorded on a number of strong motion instruments in the area. A USGS accelerometer, Gilroy station 6, was located near the Calaveras Fault in the epicentral area some 10 km southeast of the Lake Anderson landslide. Because of its proximity to the strong motion instruments, this slope failure could provide a valuable check of the validity of the seismic slope stability analyses previously developed by this project. These analyses estimate the displacements of landslide masses, given two inputs: (1) the critical acceleration for seismic-induced slope failure, a function of the slope steepness and the strength of the slope materials; and (2) the strong-motion record of the design earthquake.

Using field measurements, standard slope stability analyses, and estimates of the strength of the shale, the critical acceleration of the Lake Anderson landslide was estimated to be 15-25 percent g. Using the N. 50° E. component of the accelerograph recorded at USGS Gilroy station 6 and these critical accelerations, the expected displacements were computed to be 10-25 mm, in excellent agreement with the displacement estimated from field measurements, 20 mm. This agreement is very important because strong-motion records and well-documented slope failures rarely coincide, making physical validation of existing analytical techniques very difficult.

3. The development of criteria for mapping seismic slope stability on a regional scale continued with the revision of the seismic slope stability map of the La Honda (7 1/2') quadrangle, San Mateo County, California, previously prepared by this project and the Earthquake-Induced Landslides Project (E. L. Harp). The revisions were based on updated estimates of the relative strengths of several of the rock units in the area. The revised map is to be presented as a poster session (by G. F. Wieczorek) at the Annual Meeting of the Geological Society of America this November. This public presentation should provide criticism valuable for further development of regional zoning of seismic slope stability. In addition, a rough draft of a seismic slope stability map of San Mateo County was prepared at a scale of 1:62,500 as a feasibility study. The preparation of the county map revealed two problem areas: (1) geotechnical data is lacking or inadequate for a number of rock units, and (2) the method used to prepare slope maps from topographic data bases is a critical factor in mapping on a regional scale. These problems are being addressed in our current research.

Reports

Wilson, R. C., 1979, Numerical simulation of the interaction of strong ground motion with seismically induced landslides: Earthquake Notes, v. 49, no. 4, p. 34.

Wilson, R. C., 1979, Development of criteria for regional mapping of seismic slope stability: Geological Society of America, Abstracts with Programs, v. 11, no. 7, p. 542. (1979 Annual Meeting.)

Wieczorek, G. F., Wilson, R. C., and Harp, E. L., 1979, An experimental seismic slope stability map of the La Honda 7.5' quadrangle, San Mateo County, California: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 540. (1979 Annual Meeting.)

Harp, E. L., Keefer, D. K., and Wilson, R. C., 1979, Landslides from the August 13, 1978, Santa Barbara earthquake: California Geology, 9 p.

Preliminary effects of liquefaction potential in and near San Juan, Puerto Rico

9550-02429

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Investigations

Continued the preparation of liquefaction potential map for the San Juan, Puerto Rico, metropolitan area. Geotechnical data were further analyzed, earthquake potential was studied.

Results

Geotechnical data in preliminary liquefaction susceptibility zones were analyzed for the Bayamon, Carolina, and San Juan quadrangles, 1:20,000 scale.

Reports

No reports prepared.

Experimental mapping of liquefaction potential
9550-01629

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Investigations

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

2. Conducted additional field investigations of liquefaction generated by the November 23, 1977, Caucete, Argentina earthquake.

3. Drilled and conducted standard penetration and cone penetration tests at five sites where liquefaction occurred during the 1906 San Francicso earthquake.

Results

1. Revised and sent to the Director for approval a chapter for a professional paper. Chapter entitled "Liquefaction during the 23 November 1977 Caucete, Argentina earthquake."

2. Continued compilation of liquefaction potential map of San Mateo County, California.

3. Drilling and cone penetration and standard penetration tests at five sites where liquefaction occurred during the 1906 San Francisco earthquake revealed relatively loose layers of cohesionless soils at each site. Analysis of data to determine soil properties was begun.

Reports

No reports were published during this period.

Statistical Analysis and Geometry of Surface Faulting

9940-02086

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Investigations

1. Compilation and evaluation of data related to historic surface faulting, such as fault length and displacement, the distribution of subsidiary faults, and the magnitude, seismic moment, and focal depth of associated earthquakes.

2. Statistical analyses of the relations between and among the data listed above.

3. Bonilla is primarily responsible for compilation and evaluation of the data and R. K. Mark is primarily responsible for the statistical analysis of the data.

Results

1. Continued compilation and evaluation of historic surface faulting data, including estimates of errors in reported length and displacement. The original set of about 100 events has been reduced to 33 events, all on land, for which both the surface length and earthquake magnitude are reasonably well known. These are mostly strike-slip faults but include normal and reverse faults also.

2. For the 33 events a compilation of focal depths was made from published and unpublished sources. The actual rupture width (down-dip dimension) of 10 events could be estimated rather well from aftershocks that occurred within a few days or weeks of the faulting. Probable maximum rupture widths were estimated for 11 other events, based on focal depths of earthquakes that occurred several months to several years after the faulting. No reliable estimate of rupture width could be made for the remaining 12 events. The midpoint of the rupture surface was used as a measure of the focal depth. Focal depths estimated in this way were 8 km or less for the 10 events having aftershock data recorded within a few weeks of the faulting, and 13 km or less for the 11 events with focal depths recorded several months to several years after the faulting.

3. In order to estimate errors in surface wave magnitude, J. J. Lienkaemper did an extensive study of magnitudes of the 33 events. The individual station magnitudes listed in Beno Gutenberg's notepads (supplied by W. H. K. Lee) were averaged to estimate the errors; however Gutenberg's notes cover less than half of the 33 events. In order to treat all events as uniformly as possible, the ground amplitudes listed in Gutenberg's notes for the

earlier events, and 20 $\pm$ 2 sec amplitudes read from World Wide Network of Standard Seismograph Stations (WWNSS) records (from W. H. K. Lee's collection) for the later events were used to calculate magnitudes using the standard Prague formula of Vanek and others (1962). Modifications of this procedure were necessary for 4 events whose amplitudes were missing from Gutenberg's notes, and only local magnitudes were available for 2 small events. Magnitudes that differed from the maximum for the event by 0.6 units or more were omitted. Corrections were made for non-linearity of attenuation for station distances greater than 120°. Standard deviations in magnitudes could be determined for 30 events; they ranged from 0.08 to 0.45 and averaged 0.21 magnitude units.

4. Continued work on report on statistical considerations in using fault parameters to estimate earthquake size.

Reports

Bonilla, M. G., 1979, Historic surface faulting--map patterns, relation to subsurface faulting, and relation to preexisting faults, in Proceedings of Conference VIII, Analysis of Actual Fault Zones in Bedrock, 1-5 April 1979: U. S. Geological Survey Open-File Report 79-1239, p. 36-65.

Bonilla, M. G., in press, Comment on "Estimating maximum expectable magnitudes of earthquakes from fault dimensions": submitted to Geology, 9/27/79.

Seismological Field Investigations

9950-01539

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Investigations

1. Argentina aftershock study--regional investigation of the magnitude 7.1 (M_S) western Argentina earthquake of November 23, 1977, approximately 90 km northeast of San Juan (C. J. Langer).

2. Greece aftershock study--detailed study of the magnitude-6.4 (m_b) earthquake of June 20, 1978, which occurred in northern Greece, approximately 30 km east of Thessaloniki (D. Carver and G. A. Bollinger).

Results

1. Hypocentral locations, previously reported for the western Argentina earthquake (C. J. Langer and others, 1979), are being recomputed to obtain better depth control throughout the aftershock zone. A critical examination of the S-phase data and improved station correction values have resulted in the reduction of the hypocenter error ellipsoid. Also, it has been verified that the S-phase travel-times are anomalously fast to the east, which accounts, to a large degree, for the depth uncertainties in the preliminary hypocenter solutions.

2. A 10-station portable seismograph network was deployed to study aftershocks of the magnitude (m_b) 6.4, "Thessaloniki" earthquake of June 20, 1978. Recording commenced 13 days after the mainshock and continued for a period of 20 days. The hypocenters for 116 aftershocks, in the magnitude range 2.5 to 4.5, were determined. Epicenters for these events extended over an area some 30 km (east-west) by 18 km (north-south), and focal depths ranged mostly from 4 to 12 km. Composite focal mechanism solutions for selected aftershocks indicate reactivation of known normal faults in the area and possible splay-faulting (strike-slip and dip-slip) away from the western end of the observed surface ruptures.

Epicenters for four large ($M \geq 4.8$) foreshocks and the main shock were relocated using the JHD technique and recently available teleseismic arrival time data. Collectively, these five epicenters form an arcuate pattern that is 5 km north of the surface rupturing. That 5 km separation, along with a focal depth of 8 km (average aftershock depth) or 16 km (NEIS), implies fault plane dips for the causal fault of 58° and 73°, respectively. Also, the foreshock sequence appears to have defined the extent of surface rupturing that accompanied the mainshock.

Reports

Langer, C. J., Algermissen, S. T., Bollinger, G. A., and Castano, J. C., 1979, Aftershocks of the western Argentina earthquake (M_S = 7.2) of November 23, 1977 [abs.]: Earthquake Notes, v. 49, no. 4, p. 68-69.

A Homogeneous Alternating Markov Model for Earthquake Occurrences

14-08-0001-17766

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Description

A stochastic model is used to characterize earthquake occurrences. The model used, is an alternating Markov process which accounts for spatial and temporal dependencies of fault movement. The model provides estimates on the cumulative probability of earthquake activity over future time. In addition, probabilities of occurrence of individual events along a fault at a specified future time, are obtained. These probabilities can be useful in seismic hazard analysis.

Certain assumptions are made about the geophysical mechanisms of fault rupture. As a result, small events are not presently included in the model. The sequence of large earthquake occurrences is assumed to depend on the rate of energy accumulation and the capacity of the fault to retain the energy. An earthquake is possible when the amount of accumulated energy surpasses the capacity of the fault.

The alternating Markov process allows for transmission of energy in both time and space. First the process advances one time increment while energy is accumulated and released. At the end of the time transition (Δt), the process moves energy in the space domain. Energy can be released in any segment s_i, given that energy was released on an adjacent segment at time t. The mechanisms of release in space and time are governed by separate probability matrices. Determination of the probability of energy release during a time step, requires a combined use of both time and space transition probabilities.

In the model, future releases depend on past releases. As each major event occurs, the process is renewed. That is, after a major event, energy accumulation starts from zero on those segments that have released energy. Therefore, various portions of the fault are at different points in the evolutionary process at time t.

Results

At present, a mathetical model has been developed in which the time and space transition probabilities are homogeneous in time. However, the process could be expanded to include time varying probabilities. For purposes of preliminary testing of the model, a segment of the San Andreas Fault has been selected. Earthquake data for the years 1906 to 1976 along with qualitative observations on the earthquake mechanism for the San Andreas, were used to determine parameter values. Only events larger than magnitude 6.0 were considered. Tests were run with homogeneous time and space transition matrices for future time periods of 10 and 25 years. The probabilities of at least one event of magnitude E_j in each period were computed. In addition, the probabilities of having a specific event (E_j) at the end of the 25 year period were computed.

TITLE: Seismic Damage Assessment for High-Rise Buildings

CONTRACT NO: 14-08-0001-16814

PRINCIPAL INVESTIGATOR: Roger E. Scholl

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SUMMARY REPORT: March 1979 to October 1979

A three-year research program considers how procedures for predicting dollar losses for high-rise structures damaged by earthquakes can be improved. The problem is addressed by identification, evaluation, and correlation of ground motion data and structural parameters. Ground motion data bases, analytical techniques, and known motion-damage relationships already developed for high-rise buildings and for other classes of structures were identified early in the investigation; they will be refined and extended so that reliable quantitative seismic risk evaluations can be made.

The research effort consists of three one-year phases composed of five major tasks, as follows:

Task I	Data collection
Task II	Building categorization and calculation of theoretical motion-damage relationships
Task III	Estimation of engineering intensity from seismological intensity data
Task IV	Evaluation of empirical motion-damage relationships
Task V	Correlation of theoretical and empirical motion-damage relationships

Task I was completed during the first year (1978). Tasks II and III were initiated during the first year and are scheduled to be completed during the second and third years. Task IV was initiated during the current year and will be completed along with Task V in the third year.

Task I

The objective was to establish a data base of worldwide seismic response and damage information for high-rise buildings. Only earthquakes that had affected high-rise structures were selected for study.

Five different forms were developed to systematically record pertinent data from the following regions: North America; Latin America; Europe and the Mediterranean; and the western Pacific, which includes Japan and New Zealand. Form 1 provides general earthquake data; Form 2, motion and damage data; Form 3, site information; Form 4, building categorization; and Form 5, detailed site and building information such as soil-test boring logs or design calculations. Collected data essential for the study include strong-ground-motion parameters, soil characteristics, estimated damage, design parameters, building categorization, and geographical location. For selected areas, seismological data, information on construction codes and practices, and other general data were collected. The computerized data-base system HIRISE was established using the information collected on the forms. The data base facilitates access and retrieval of data in any order or arrangement desired, thus simplifying the correlation procedure.

Initially, the study focused on collection of data for specific buildings, primarily those damaged during each earthquake. Information on the characteristics of each building and on the damage it had sustained was stored in the data base HIRISE. When the data base was established, space was left to accommodate additional information, such as statistical data on the undamaged buildings in each area, that is necessary for reconstruction of a realistic damage scenario, and data on overall seismicity, distribution of soil types, density of high-rise buildings, and intensity distributions for each earthquake, all needed to construct a profile for each area.

During the second year of study, the data base was reviewed and updated. Subsequent efforts focused on the completion of a profile for each urban area under investigation. For this task, soil maps, street maps, aerial photographs, and intensity maps of the various areas are being used to establish a grid for each city, dividing it into sections with similar soil and motion intensity characteristics.

Task II

The task of building categorization has been completed. Categories were established on the basis of structural systems: foundation system, vertical-load-support systems, lateral-load-resisting systems, and floor systems, the most important for seismic resistance being the lateral-load-resisting systems. Structural and architectural materials were also considered. Architectural materials, although not designed specifically to do so, contribute in varying degrees to lateral-load resistance and are important for damage evaluation. The degree of contribution depends not only on the types of materials used but also on the framing characteristics of building systems. Building configuration was analyzed because irregularity in plan and elevation may result in torsional response or have other secondary effects. Torsional response may also occur because of eccentric location of either the building masses or the lateral-load-resisting elements. Each of these items was recorded on Form 4.

Damage factors for both structural and nonstructural building components are currently being calculated on the basis of theoretical studies. Starting with detailed tridimensional mathematical structural models of selected buildings for which motion was recorded and damage is known, an exhaustive procedure of structural analysis is carried out. The onset of nonlinear behavior that can be related to damage is identified with instantaneous transfer functions obtained from accelerograms. The instantaneous transfer functions are also valuable in identifying variability in structural parameters during the earthquake's duration. From information about the transient nonlinear behavior of the structure inferred from these instantaneous transfer functions, the mathematical models are calibrated and adjusted. Taking into account the reported damage, simple global damage indicators in the theoretical damage-motion relationships being developed are then tested. The global responses currently under evaluation include interstory drift, interstory strain, base shear, ductility, and structural deformation.

Task III

Substantial progress is being made toward relating seismological intensity to engineering intensity. Initial results based on published data have been compiled, and some conclusions have been drawn. It is evident, for example, that further consideration should be given to seismological and geological factors such as distance, magnitude, and local geology; as investigation continues, the data base HIRISE will be used to check the relationships among these factors. As more records become available, their velocity response spectra with 5% damping will be used directly to obtain corresponding engineering intensities.

Task IV

At the same time, various empirically derived motion-damage relationships are being tested with the data base HIRISE. Damage factor and damage ratio (the latter defined as the ratio of the number of buildings damaged to the total number of buildings in an area shaken by an earthquake) are functions of the global parameters mentioned above and of indicators of seismic motion such as MMI level, Richter magnitude, and, in particular, EIS level. These empirical motion-damage relationships also take into account building categorization, soil types, and local construction practices.

Reports

URS/John A. Blume & Associates, Engineers, *Seismic Damage Assessment for High-Rise Buildings; Semiannual Technical Report: October 1978*, San Francisco, 1978.

_____, *Seismic Damage Assessment for High-Rise Buildings; Annual Technical Report: April 1979*, San Francisco, 1979.

_____, *Seismic Damage Assessment for High-Rise Buildings; Semiannual Technical Report: October 1979*, San Francisco, 1979.

A Stochastic and Bayesian Model for Seismic Hazard Mapping and for Estimating Earthquake Losses

14-08-0001-17767

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Investigations

During the period of February 15, 1979 to May 31, 1979, the following tasks were investigated under the subject project.

1. Development of stochastic model for Risk Analysis with geophysical input

2. A critical look at the currently used Bayesian models in seismic risk analysis. Development of priors based on theoretical geophysical models and on subjective knowledge of experts

Results

1. A geophysical model of ground motion simulation is used to generate the statistics of the power spectral density (PSD) of the acceleration at the bedrock level of a site. A non-stationary Poisson model of occurrences is then developed to combine the effects of all the probable sources in the seismic zone of interest. The consistent probability PSD is computed as a basic design parameter. Consistent probability peak response spectra, RMS response spectra, and pseudo time histories are also derived as design parameters. A numerical example is given for a site in Southern California to demonstrate the applicability of the method.

2. The major effort in task II above during this period has been in evaluating the role of Bayesian Models in seismic hazard mapping. The first and foremost need was to understand the following points as they relate to the Bayesian models:

Results (Cont.)

a. Definition of the overall seismic hazard methodology. Concern for using only the historical seismicity data for seismic hazard mapping. Role of Bayesian models to partially alleviate these concerns.

b. What are the Bayesian models? What are prior distributions, sample likelihood functions and posterior distributions? What are the conditions under which these models can be used?

c. What is a true prior in the Bayesian Context? Can one use objective information as a prior? How can one obtain this prior? Is it realistic to encode the subjective information of experts?

d. Develop an understanding of the problems and difficulties in using the Bayesian model for seismic hazard mapping.

e. Where do we go from here?

A complete progress report for the second task and a copy of the paper written for task I are sent to the sponsoring organization.

Papers

Savy, J.B. and Shah, H.C.; "A Nonstationary Risk Model for Geophysical Input". Paper accepted for Publication in ASCE, Journal of Structural Division.

Loss Assessment Sensitivity of Alternative Risk Mapping Procedures

8-0001-18204

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The purpose of this study is to evaluate the effects of various seismic hazard mapping procedures on economic loss projections. Three hazard maps will be used: (1) the Algermissen and Perkins (1976) map; (2) the ATC-3 (1978) map; and (3) the J.H. Wiggins Company map (1975). Loss projections will be made using the J.H. Wiggins Company exposure model for the United States. This model describes the building wealth of the United States by type, value, age, and quality of construction for each county. The results of this study will help to (1) demonstrate the sensitivity of loss estimates to risk mapping procedures; (2) guide future map makers in developing criteria for caution regarding the development and use of their map; and (3) identify regions which require concentrated earthquake hazards study as well as those which may be disregarded because of their low seismicity or insignificant exposure.

The project is made up of six major tasks:

- Task I — Evaluation and digitization of the three seismic hazard maps.
- Task II — Digitization of the building wealth - exposure model.
- Task III — Identification of potential users of the exposure model.
- Task IV — Computation of annualized loss estimates based on each seismic hazard map.
- Task V — Subregionalization of loss estimates.
- Task VI — Sensitivity analysis.

Tasks I, II and III have been completed during this first six-month period. Tasks IV and VI have been initiated and are scheduled to be completed by the end of this year. The completion of Task V will result sometime within the completion of Task IV.

Under Task I, the major accomplishment has been the completion of the digitization of the three seismic hazards maps. Peak ground accelerations (reflecting a 475-year return period in all cases) have been tabulated for each county seat in the contiguous United States. These accelerations have been coded for each map and are recorded on computer cards. We are using the county seats as grid points since the exposure model was prepared on a county level. Use of the county seat as the grid point location is recommended for simplicity, and

*Principal Investigator

since the county seat is approximately the center of population, it should be representative of the center of building exposure. Our sensitivity study will check this assumption. Peak ground motions were compiled for 3107 counties.

Another major accomplishment under Task I has been the development of the methodology that will be used to derive intensity-recurrence relations at each county for the various hazard maps. The methodology was derived in a general manner for application in future seismic hazard map generation, and then simplified for application to the three maps involved in this study. During our evaluation, we found that the recurrence relations were very sensitive to the particular intensity versus acceleration relations used. Furthermore, we found that conversion of peak hard-rock acceleration values to intensity observed at the soil surface requires use of "dynamic amplification factors" in order to accurately predict the observed intensity values in one area (San Diego). Without this correction, the recurrence relations derived from the hard-rock acceleration hazard maps seriously underestimate the frequency of occurrence of damaging earthquakes in the San Diego area. We have not yet checked this effect for other areas.

Under Task II, we have completed the digitization of the county exposure model. The county data tape developed by the J.H. Wiggins Company under a National Science Foundation Grant has been recoded to appear in a format that can be used by other organizations. Information on the tape includes population estimates, population projections, locally assessed values (1971 dollars), structure value per capita data and projected income per capita data. This information is available for 3132 counties in the United States (including Alaska and Hawaii).

Under Task III, potential users of the exposure model have been identified. This list includes economists, scenario analysts, public administrators, the Federal Disaster Aid Administration (FDAA), Federal Emergency Management Administration (FEMA) and others.

A computer program has been developed under Task IV which will compute annualized building losses from the information made available in Tasks I and II. This program will be verified during the second six-month period.

Some theoretical considerations for the sensitivity study (Task VI) have also been made. These will be useful in designing computational experiments to demonstrate the effects various risks mapping procedures have on the final economic loss projections.

Research Applications

9900-90027

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Investigations

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

Results

1. The Office of Earthquake Studies is continuing to contribute to the activities of the Interagency Committee on Seismic Safety in Construction, which was formed in December, 1978. This committee is developing a common set of standards, codes, and practices to use for all federal construction. The target is to have these standards, codes, and practices ready for "trial use" by mid-1980.

2. The Office of Earthquake Studies co-sponsored with Federal Emergency Management Agency, National Science Foundation, and Department of Energy the 1979 Summer Institute on "Multiprotection Design for Architectural and Engineering Facilities." The Institute was held in Battle Creek, Michigan in August. Institute preoceedings are available.

3. The Office of Earthquake Studies assisted the Department of Energy (DOE) to develop a research program plan for Geothermal Induced Seismicity. This plan was completed in September and will be published by DOE.

4. In September, members of the Office of Earthquake Studies participated in a "cluster" meeting with State Geologists from the central region to discuss State and Federal programs and ways to cooperate.

Reports

Hays, W. W., 1979, Program and plans of the U.S. Geological Survey for producing information needed in national seismic hazards and risk assessment, Fiscal Years 1980-84, U.S. Geological Survey Circular 1816, 65 p.

Central American Seismic Studies

9930-01163

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Investigations

Cooperative programs are continuing between the USGS and government agencies in Guatemala and Nicaragua to establish and operate earthquake research institutes. The goal of this project is to search for precursory phenomena in seismicity patterns preceding earthquakes of magnitude 5.0 and larger. Current emphasis is on the close monitoring of seismic activity in the vicinity of a seismic gap near the Pacific coast of Nicaragua. This effort, however, has been interrupted by the recent change in the Nicaraguan government.

Results

In a previous study (see report below) analysis of data between April 1975 and December 1978 revealed an area of seismic quiescence near western Nicaragua. These results also suggested that seismic activity along the edges of the quiet zone was increasing. A preliminary plot of earthquake epicenters for the period January through May 1979 indicates that the quiet zone continues to be seismically inactive, but the seismic activity along the edges has not continued to increase and may actually have decreased slightly.

Reports

Harlow, D. H., White, R. A., Cifuentes, I. L., and Aburto, A., Quiet zone within a seismic gap near western Nicaragua: Possible location of a future large earthquake: (Submitted to Science, October 1979).

Heat Flow and Tectonic Studies

9960-01176

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Investigations

1. Heat-flow map of the United States. An up-to-date version of the heat-flow map has been produced.

2. Heat flow and tectonics of the southern Basin and Range province. Several dozen new heat flows from the Sonoran Desert of Arizona and eastern California are being put in final form. Six deep holes (1 to 1.5 km) drilled by DOE-Nuclear in sedimentary basins have been cased for heat-flow measurements.

3. Heat flow and tectonics of the Garlock fault zone. About ten additional holes were drilled in an attempt to characterize the heat flow of the Garlock fault zone.

4. Heat flow and tectonics of the San Andreas fault. Interpretation is proceeding on the ∿100 heat-flow data available from the San Andreas fault zone between Cape Mendocino and the Salton Sea.

5. Heat flow and tectonics of the Northern Great Basin. Data obtained during the past two years are being interpreted and tabulated. Heat-flow data from the Black Rock Desert have been interpreted and compared with other geophysical data.

6. Instrument development. Minor design changes have been made to the downhole heat-flow probe. Development and evaluation continue on a) a portable digital-logging system, b) a battery-powered temperature-monitoring system for remote locations, and c) a simple linear temperature transducer.

7. Heat-flow measurements in Alaska. During the summer of 1979, temperatures were measured at an additional ∿30 sites drilled for mining and oil exploration.

Results

1. In cooperation with other heat-flow groups, an up-to-date version of the heat-flow map of the United States (Figure 1) was prepared for inclusion in the new "Handbook of Physical Constants." (This publication will also have more detailed regional maps.) The gross features of the map have not changed significantly as compared with earlier versions, but several new regions of higher-than-normal heat flow (hatched, Figure 1) have emerged in the east. In the west (Figure 2) many significant new details are apparent.

There is a newly defined high associated with the southern Cascades, and the Battle Mountain high (BMH, Figure 2) has been extended to link up with the Brothers fault zone anomaly in southeastern Oregon. A hydrologic heat sink has been delineated in the eastern Snake River Plain (SRP, Figure 2), and there are some newly defined heat-flow highs associated with the margins of the Colorado Plateau.

2. Heat flow from the bedrock of the Sonoran Desert in Arizona and southeastern California is high and variable, averaging about the same ($\sim$2 HFU) as that for the Basin and Range province as a whole. Some areas of high heat flow coincide approximately with zones interpreted (from aeromagnetic data) as having a shallow Curie isotherm. In this region, a detailed study was made near the Saline Valley KGRA. The lack of recent volcanism in the area and the apparently normal Basin and Range heat flow suggest that geothermal systems within the valley are stable stationary phases supported by the high regional heat flow and forced convection.

3. The average heat flow from about a dozen holes within 10 km of the Garlock fault zone is significantly higher than that in the Mojave block or that part of the San Andreas fault zone forming the southern boundary of the Mojave block. There is, however, no clear-cut evidence for a peaked heat-flow anomaly centered on the main trace of the Garlock fault.

4. North of Cape Mendocino, heat flow is low (1.0 HFU), and it rises over a distance of about 200 km southward, to an average of about 2.0 HFU characteristic of the remaining 550 km of the California Coast Ranges. Heat flow is significantly lower (1.6 HFU) farther south along the 150-km fault segment that bounds the Mojave block. No evidence for a local heat-flow anomaly due to fault friction exists at any latitude. Thermal springs near the fault are inadequate to remove significant frictional heat. Our study confirms earlier results; the average (dissipative) frictional resistance in the seismogenic layer of the fault is probably less than 100 bars. If, as is often reported, the seismic stress drop and apparent stress are substantially less than 100 b, then the local tectonic stress and fault strength are small ($\sim$100 b), and steady-state super-hydrostatic fluid pressure probably obtains. Growth of the broad Coast Range anomaly southward from Cape Mendocino could be a transient effect of northward migration of the Triple Junction. If so, most of the resistance to plate motion may not be on the fault but on horizontal surfaces which partially decouple the brittle seismogenic layer from more ductile lower crust in a broader interplate shear zone.

5. Recent heat-flow measurements in the Northern Great Basin have left the eastern and southern boundaries of the Battle Mountain high (BMH, Figure 2) substantially unchanged but have resulted in significant revisions to its western margins. Near the western margin of the BMH, the southern Black Rock Desert is a complex hydrothermal convection system with a combined conductive and convective heat flux greater than 2.5 HFU, justifying its inclusion in the BMH. Neither young volcanic activity, nor "thermal blanketing" by low-conductivity sediments can be invoked to explain the existence of the numerous hot springs in the region. Heat flow and microearthquake data suggest that the activity results from deep (4-7 km) circulation of meteoric water in fractured basement rocks.

6. The downhole heat-flow probe was deployed in support of a heat-flow study of the Mono Lake Known Geothermal Resources Area. The major mechanical and electronic components of a portable digital temperature-logging system have been assembled and tested. This system will be modified for use in monitoring temperatures in wells near the San Andreas fault. A new integrated circuit having a linear temperature response, an accuracy of ~0.01°C and requiring only a two-conductor cable is being evaluated as an alternative temperature-logging system for applications not requiring the higher accuracy (±.001°C) of our thermistor-based logging system.

Reports

Curray, J. R., Moore, D. G., Lawver, L. A., Emmel, F. J., Raitt, R. W., Henry, M., and Kieckhefer, R., 1979, Tectonics of the Andaman Sea and Burma, in Watkins, J. S., Montadert, L., and Dickerson, P. W., eds., Geological and Geophysical Investigations of Continental Margins: American Association of Petroleum Geologists Memoir 29, p. 189-198.

Lawver, L. A., and Williams, D. L., 1979, Heat flow in the central Gulf of California: Journal of Geophysical Research, v. 84, p. 3465-3478.

Mase, C. W., Galanis, S. P., Jr., and Munroe, R. J., 1979, Near-surface heat flow in Saline Valley, California: U.S. Geological Survey Open-File Report 79-1136, 52 pp.

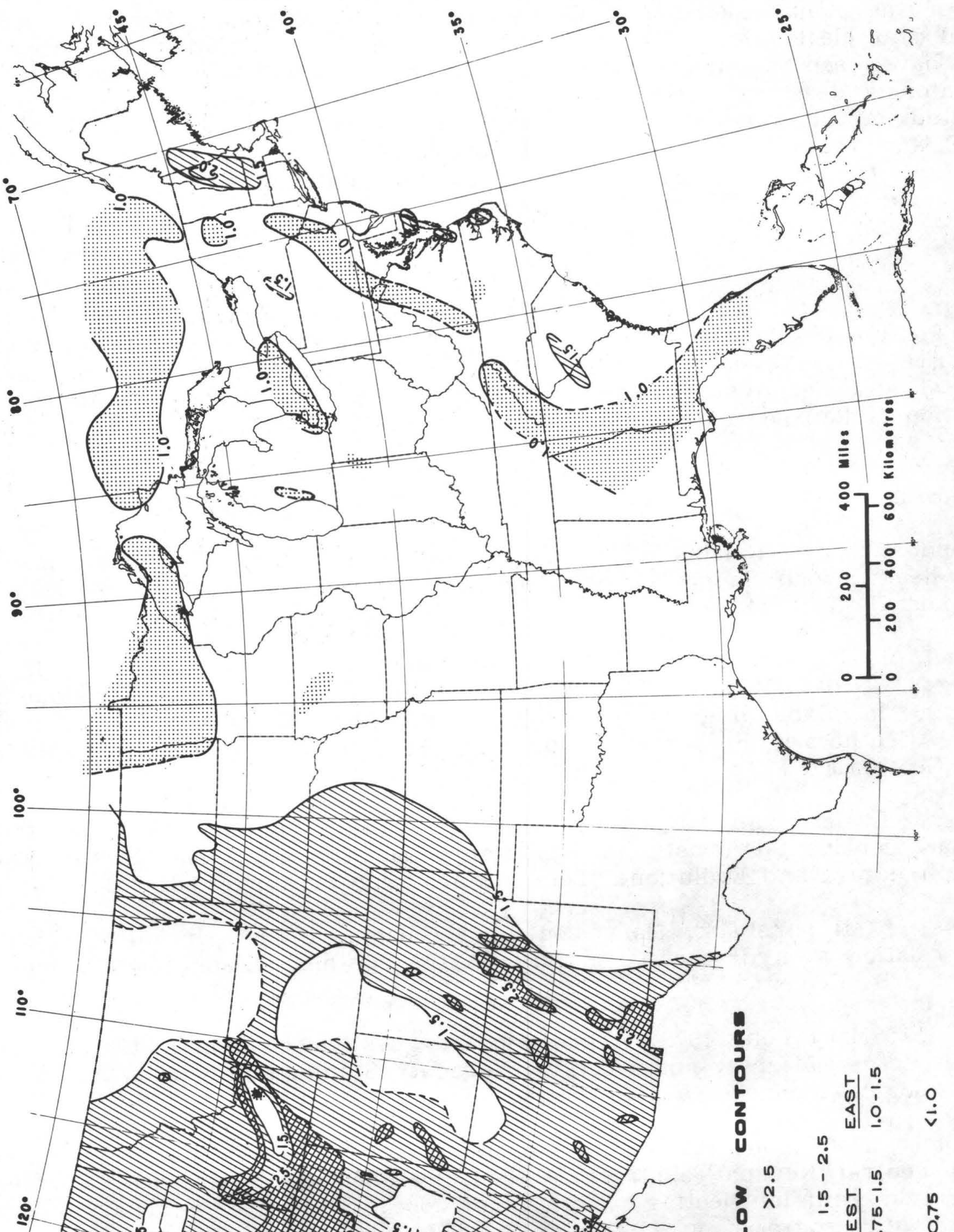
Sass, J. H., Kennelly, J. P., Jr., Wendt, W. E., Moses, T. H., Jr., and Ziagos, J. P., 1979, In situ determination of heat flow in unconsolidated sediments, in Expanding the Geothermal Frontier, Transactions, Annual Meeting, Geothermal Resources Council, (Reno, Nevada, September 24-27, 1979): Geothermal Resources Council, v. 3, p. 617-620.

Sass, J. H., and Lachenbruch, A. H., 1979, Thermal regime of the Australian continental crust, in McElhinny, M. W., ed., The Earth: Its Origin, Structure and Evolution: London, Academic Press, p. 301-351.

Sass, J. H., Zoback, Mary Lou, and Galanis, S. P., Jr., 1979, Heat flow in relation to hydrothermal activity in the southern Black Rock Desert, Nevada: U.S. Geological Survey Open-File Report 79-1467, 39 pp.

Zoback, Mary Lou, 1979, A geologic and geophysical investigation of the Beowawe geothermal area, north-central Nevada: Stanford University Publications, Geological Sciences, v. 16, 79 pp.

Zoback, Mary Lou, 1979, Direction and amount of late Cenozoic extension in north-central Nevada (abstract): Geological Society of America, Cordilleran Section, Annual Meeting., 75th, San Jose, California, February 1979, Abstracts with Programs, v. 11, no. 3, p. 137.


HEAT FLOW CONTOURS
>2.5
1.5 - 2.5
WEST
EAST
0.75-1.5
1.0-1.5
< 0.75
<1.0
< 0
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45°
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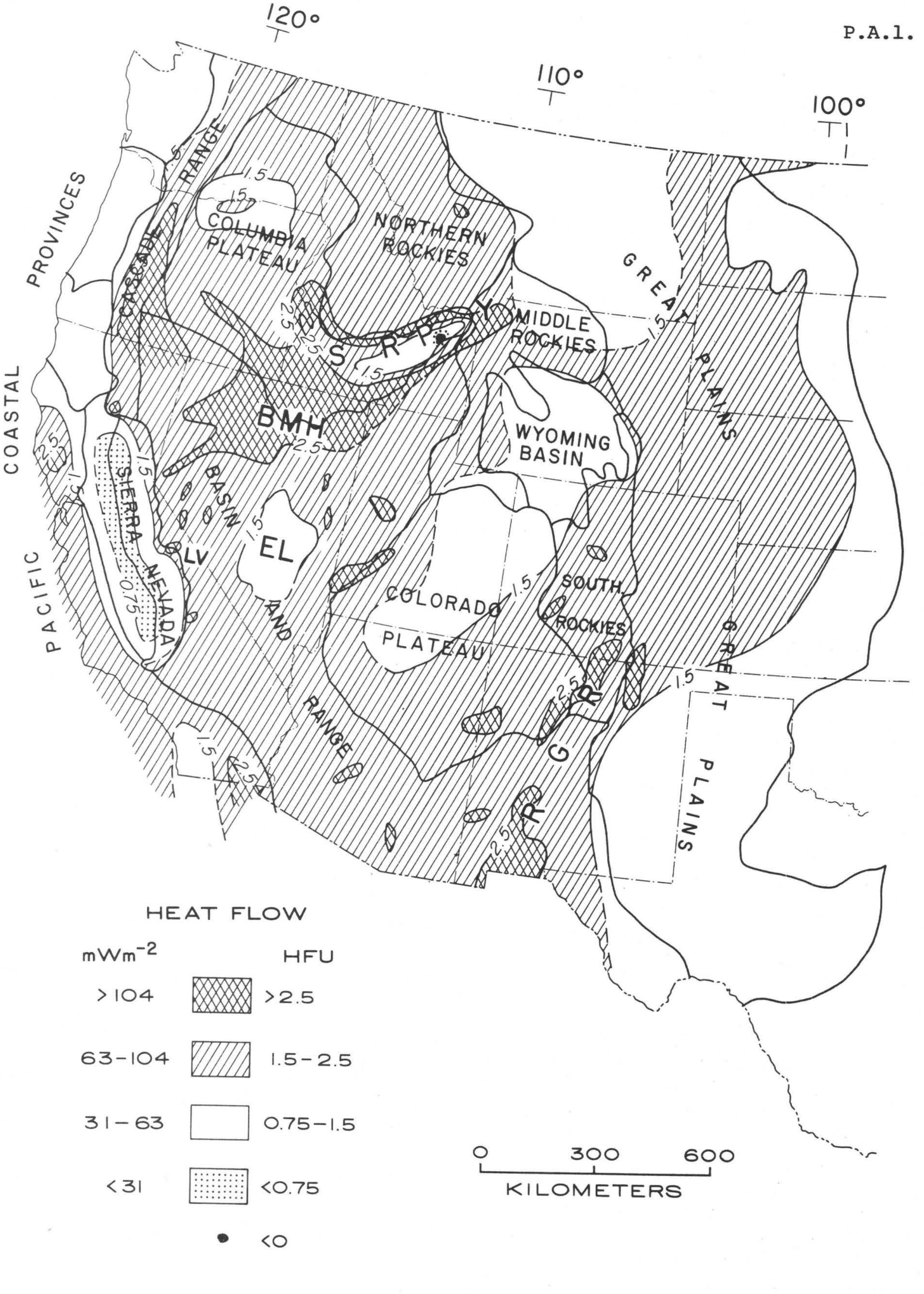

Figure 2. Map of the western United States showing heat-flow contours, heat-flow provinces, and major physiographic divisions. SRP, Snake River Plain; BMH, Battle Mountain high; EL, Eureka Low; RGR, Rio Grande Rift zone; Y, Yellowstone; LV, Long Valley.

UNIVERSITY OF SOUTHERN CALIFORNIA
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SUMMARY REPORT

U. S. G. S. Contract No. 14-08-0001-16895

Earthquake Prediction Research in Taiwan

January 25, 1979 to July 23, 1979

Charles G. Sammis, Tien C. Lee; Principal Investigators

Radon Project

We have completed the construction of two radon boards for liquid nitrogen cold-trap radon gas purification. Four scintillation cells have also been fabricated at USC. Presently, work is in progress constructing the α-counting equipment which includes a high-voltage power supply, pulse counter, recorder, and basic housings for the photomultiplier tube. These housings, being made in our machine shop, have the same design as those used in the NSF/IDOE radon program. We expect to complete the construction of the entire radon counting system by late October, 1979, and to install the system in the Chinese Earthquake Research Center in Taiwan by early November, 1979.

Professor W. L. Cheng, a geochemist, will be in charge of the radon project in Taiwan. Under the direction of Professor Yi-Ben Tsai, a dozen or so hot springs have tentatively been selected as potential sampling sites. Our colleagues in Taiwan have also completed the construction of about fifty ground water sample bottles. Actual radon monitoring work should start as soon as the radon counting system is delivered in November of 1979.

Geodetic Measurements

A HP-3808A medium range distance meter and all necessary accessories are being ordered, delivery time will be the fall of 1979. Meanwhile, Professor Yi-Ben Tsai has made arrangements for one of his staff members, Mr. Teh-Quei Lee, to come to the US to get acquainted with the HP instrument. Arrangement has been made with Dr. Jim Savage for Mr. Lee to participate in the USGS geodetic survey so as to gain first-hand experience. A preliminary network of geodetic bench marks in eastern Taiwan are being finalized for construction.

Magnetic Measurements

After several site inspections and field observations, two base stations for geomagnetic observations have been established. One station (LP) is located in the observatory of the Institute of Taiwan Telephone and Telegraph Company, Lun Ping, northern Taiwan (25°00'N, 121°10'E); the other station (TW) is located at Wan Chu, near the City of Taiwan, southern Taiwan (23°11.25'N, 120°31.35'E). Station LP is in the area believed to be seismically stable and station TW is in the unstable area. Continuous recordings at the stations have been obtained since May.

A network of geomagnetic stations has also been established. Those stations have been reoccupied periodically with portable Geometric proton magnetometers. Readings of the portable magnetometers have been calibrated with respect to the readings of base magnetometers.

We have encountered some instrument failures. One of the two base magnetometers has been repaired by the manufacturer.

Tien Lee is visiting Taiwan to attend a conference on Taiwan earthquakes and to assist in on-site studies.

Earthquake Hazards Determinations Based on the Tectonic Stress Measurements

14-08-0001-16773

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Investigations

The objectives of this research program are to (1) determine the spatial and temporal variations of the recoverable tectonic stress in the Southern California section of the San Andreas fault system; (2) to identify spatial regions as hazardous in terms of the predicted size and locations of large earthquakes based on the recoverable stress levels inferred and (3) to attempt to predict times of failure based on time variations in the stress levels. In this context the terms "recoverable tectonic stress" refers to that part of the nonhydrostatic stress field within the earth that can be released by an earthquake and is commonly referred to as the "stress drop" in observational seismology.

The approach to the estimation of the recoverable stress is to use observations of the seismic radiation from the numerous very small (local magnitudes M_L near two) to moderate sized earthquakes ($M_L \sim 4.0$), in the tectonic region of interest, to infer the stress changes associated with these events. The stress changes are largely local to the failure zone, in view of the rapidity of stress change fall-off with distance, and, for these small events, constitute perturbations to the regional stress field. The changes can, however, be used to provide a sampling of the regional stress and hence provide the desired stress sampling procedure.

Results

1. Acquisition of a large appropriately selected seismic data base consisting of several hundred small magnitude earthquakes in the Southern California region and recorded digitally at from 20 to 50 seismic stations in the Southern California Seismic Array.

2. Design and implementation of a series of data processing and time series analysis programs has been completed to provide a reasonably automated procedure for selection and analysis of the sesimic array data.

3. Calibration of the entire Southern California Array has been completed, so that the appropriate instrument transfer functions and station receiver gain factors are now available for use in correcting the observed spectral data to give true, absolute ground motion. These ground motion observations are now being used to inferr event stress drops directly.

4. A new method for the generation of complete theoretical seismograms, employing a "locked mode" approximation, which is nearly exact in practice, has been developed. The flexibility of the method, both for incorporating frequency dependent energy absorption by the medium and for source inversion, makes it a particularly appropriate method for the study of source properties in the near and regional distance ranges.

5. A general inverse theory for earthquake sources has been developed. The theoretical results are such that the time evolution of the stress drop (or recoverable stress) as a function of failure growth can be determined. This theory allows for inferrence of both time and spatial variability in the stress drop.

6. An exact theoretical solution for the problem of stress wave radiation in the vicinity of a instantaneously created spherical failure in an inhomogeneously prestressed (i.e., prestress arbitary) medium has been obtained. The problem represents a canonical solution for more general failure zones of more conventional geometry (elliposoidal) and failure rates (finite) since it serves to delineate the nature of the effects of scattering from the failure surface (non-transparent source) and, most important, the effects to be expected from strongly inhomogenous prestress. The results show that strong peaking of the earthquake spectra is likely for strongly inhomogeneous prestress and that corner frequencies can also shift drastically from that predicted for a homogeneously prestressed medium.

Reports

Archambeau,C.B., Estimation of non-hydrostatic stress in the earth by seismic methods: Lithospheric stress levels along the Pacific and Nazca plate subduction zones, Proceedings of Conference VI, National Earthquake Hazards Reduction Program: Methodology for Identifying Seismic Gaps and Soon-to-Break Gaps, U.S. Geological Survey Open File Report 780943, May, 1978, submitted to Geophys. J. Roy. Astron. Soc., 1979.

Archambeau, C.B. and J.L. Stevens, Elastodynamic Source Inversion, abstract, EOS, Amer. Geophys. Union, 1978, to be submitted to Geophys. J. Roy. Astron. Soc., 1979.

Archambeau, C.B., J.M. Savino and J. Masso, Time Series Analysis Based on Quasi-Harmonic Decomposition (QHD): Applications to Seismic and Other Vector Wave Fields, to be submitted to J. Geophys. Res., 1979.

Harvey, D., Seismogram Synthesis Using Normal Mode Superposition: The Locked Mode Approximation Method, Geophys. J. Roy. Astron. Soc., 1979, In press.

Stevens, J., Seismic Radiation from the Sudden Creation of a Spherical Cavity in an Arbitrarily Prestressed Elastic Medium, EOS, vol. 59, No. 12, p. 1139, 1978, Geophys. J. Roy. Astron. Soc., 1979, in press.

PALEOGEODETICS

9960-01488

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Investigations

Analysis and interpretation of repeated geodetic survey measurements relevant to earthquake related deformation processes occurring at or near major plate boundaries. Principal recent activities have been (1) an analysis of historic geodetic measurements on the northwestern margin of the Southern California Uplift and their relation to the Quaternary geologic structure of the region and (2) the identification of a region of localized tectonic downwarping in Northern Honshu, Japan - as a result of earthquake-induced flow in the asthenosphere.

Results

1. Synthesis of geodetic, geologic, and seismic data from the northwestern margin of the southern California uplift indicates that the White Wolf fault separates an area of late Quaternary and continuing rapid uplift in the Tehachapi Mountains from even more rapid subsidence in the southern San Joaquin Valley (Stein et al, 1979). The geodetic record since ∿1900 reveals two episodes of uplift and partial collapse coincident with regional uplifts in southern California. Reconstruction of the throw on the White Wolf fault from stratigraphic marker beds affords comparison with the geodetic record: the rate of fault throw increased markedly in the most recent 0.6 - 1.2 My to 4-9 mm/yr, and the 1952 M7.7 earthquake appears characteristic of the late Quaternary record of fault displacement, with a recurrence interval of ∿200-400 years being indicated. The rates of fault throw, emergence of the Tehachapi Mountains, and subsidence of the southern San Joaquin Valley measured during the past 73 years have been three or four times higher than those during the past ∿1 My, at least in part, reflecting the occurrence of the 1952 earthquake during this recent time interval.

2. In ideal situations, the time-dependent level changes due to asthenospheric readjustments that are predicted to follow large thrust-type earthquakes (Thatcher and Rundle, 1979) can be used to independently constrain the effective elastic thickness of the lithosphere and the viscosity of the asthenosphere. For these purposes, intraplate earthquakes are better than great plate boundary events, and the 1896 M 7-1/2 Riku-u earthquake, in northern Honshu, demonstrates the importance of the asthenospheric relaxation process and provides rather tight parameter constraints (Thatcher et al., 1979). A leveling route that crosses the 1896 surface ruptures has been surveyed five times since 1900 and delineates a localized depression that has subsided at a continually decreasing rate. The depression is associated unmistakably

with the 1896 faulting, and its width, about 75 km, determines the lithospheric thickness as 30 km. The decaying rate of subsidence constrains the asthenospheric viscosity to be 4×10^{20} Poise, quite consistent, for example, with the value determined from the isostatic rebound of Lake Bonneville, Utah.

Reports

Stein, R. S., W. Thatcher and R. O. Castle, 1979, Late Quaternary and modern deformation along the fault-bounded northwest margin of the southern California Uplift, J. Geophys. Res., submitted 1979.

Thatcher, W., Systematic inversion of geodetic data in central California, J. Geophys. Res., 84, 2283-2295, 1979a.

______, Horizontal crustal deformation from historic geodetic measurements in southern California, J. Geophys. Res. 84, 2351-2370, 1979b.

______, Crustal movements and earthquake-related deformation, Revs. Geophys. Space Phys., in press, 1979c.

______, and J. B. Rundle, A model for the earthquake cycle at underthrust zones, J. Geophys. Res., 84, 5540-5556, 1979.

______, T. Matsuda, T. Kato, and J. B. Rundle, Lithospheric loading by the 1896 Riku-u earthquake, Northern Japan: implications for plate flexure and asthenospheric rheology, J. Geophys. Res., submitted, 1979.

Rundle, J. B., and W. Thatcher, A stress relaxation model for the southern California uplift, EOS, 60, 321, 1979.

In-Situ Stress Measurement
9960-01184

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In-Situ Measurements

A variety of geophysical measurements were made in a 1-km deep well located in granite, 4 km northeast of the San Andreas fault in the western Mojave Desert. The well in which the measurements were made was drilled in 1961 to test for petroleum. The drilling rig of the Fault Zone Studies Program was used to reclaim the well and conduct the downhole tests. Repeated attempts to measure in-situ stress by hydraulic fracturing were largely unsuccessful because of the highly fractured nature of the rock, but one partially successful measurement was made at a depth of 400 m. Previous measurements made in the region suggested that the average frictional strength of the seismogenic part of the San Andreas fault is as low as 50-60 bars. The new measurement suggests somewhat higher stresses may exist on the fault. An extensive study of the fracture systems present in the well, as well as a detailed study of the seismic velocity and attenuation of the fractured granitic rocks, was made.

Stress Map

An interpretative stress map of the coterminous United States has been prepared using geologic data, earthquake focal mechanisms, and in-situ stress measurements (Fig. 1). In the tectonically active western United States, the stress pattern is complex but numerous stress provinces can be well defined that agree remarkably well with the physiographic provinces. In the relatively quiescent eastern and central United States, the state of stress is definitely not uniform, and the boundaries of the stress provinces are again found to agree well with the physiographic boundaries. The pattern of stresses in the crust are found to be consistent with stresses generated by the following sources: plate interactions (along the Pacific Coast), asthenospheric resistance to plate motion (central United States), ridge-push forces acting at a passive continental margin (eastern seaboard), density differences in regions of abrupt changes in lithosphere/asthenosphere structure (basin and range/Rio Grande rift and the Colorado plateau/southern Great Plains), and sediment loading (Texas Gulf coast).

New Madrid

Preliminary analysis of 280 km of seismic reflection profiling has been completed. Several major faults were found which can be correlated with trends in current seismicity and evidence was found of repeated episodes of igneous activity, the latest being in Tertiary time.

Reports

Zoback, M. D., Roller, J. C., Seeburger, D., and Svitek, J., 1979, Hydraulic fracturing stress measurements and strength of the San Andreas fault in the Western Mojave Desert: submitted to Journal of Geophysical Research.

Zoback, M. L., and Zoback, M. D., 1979, Interpretative stress map of the coterminous United States: submitted to Journal of Geophysical Research.

Zoback, M. L., and Zoback, M. D., 1979, Interpretative stress map of the coterminous United States (abs.): American Geophysical Union Fall Meeting, San Francisco, December 1979.

Moos, D., and Zoback, M., 1979, Seismic properties of fractured granites to a depth of 1 km (abs.): American Geophysical Union Fall Meeting, San Francisco, December 1979.

Zoback, M. D., Roller, J. C., Svitek, J., Seeburger, D., and Amick, D. C., 1979, The mechanism of induced seismicity at Monticello Reservoir, South Carolina: in-situ studies at hypocentral depth (abs.): American Geophysical Union Fall Meeting, December 1979.

Zoback, M. D., 1979, In-situ measurement of parameters relevant to earthquake occurrence (abs.): Bulletin of the Geological Society of America.

Zoback, M. D., Hamilton, R. M., Crone, A. J., Russ, D. P., and Brockman, S. R., 1979, Recurrent intraplate tectonism in the New Madrid seismic zone: to be submitted to Science.

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

Zoback, M. D., Hamilton, R. M., Crone, A. J., Russ, D. P., and Brockman, S. R., 1979, Major fault zone associated with the main New Madrid seismic trend shown by seismic-reflection profiling: Earthquake Notes, in press.

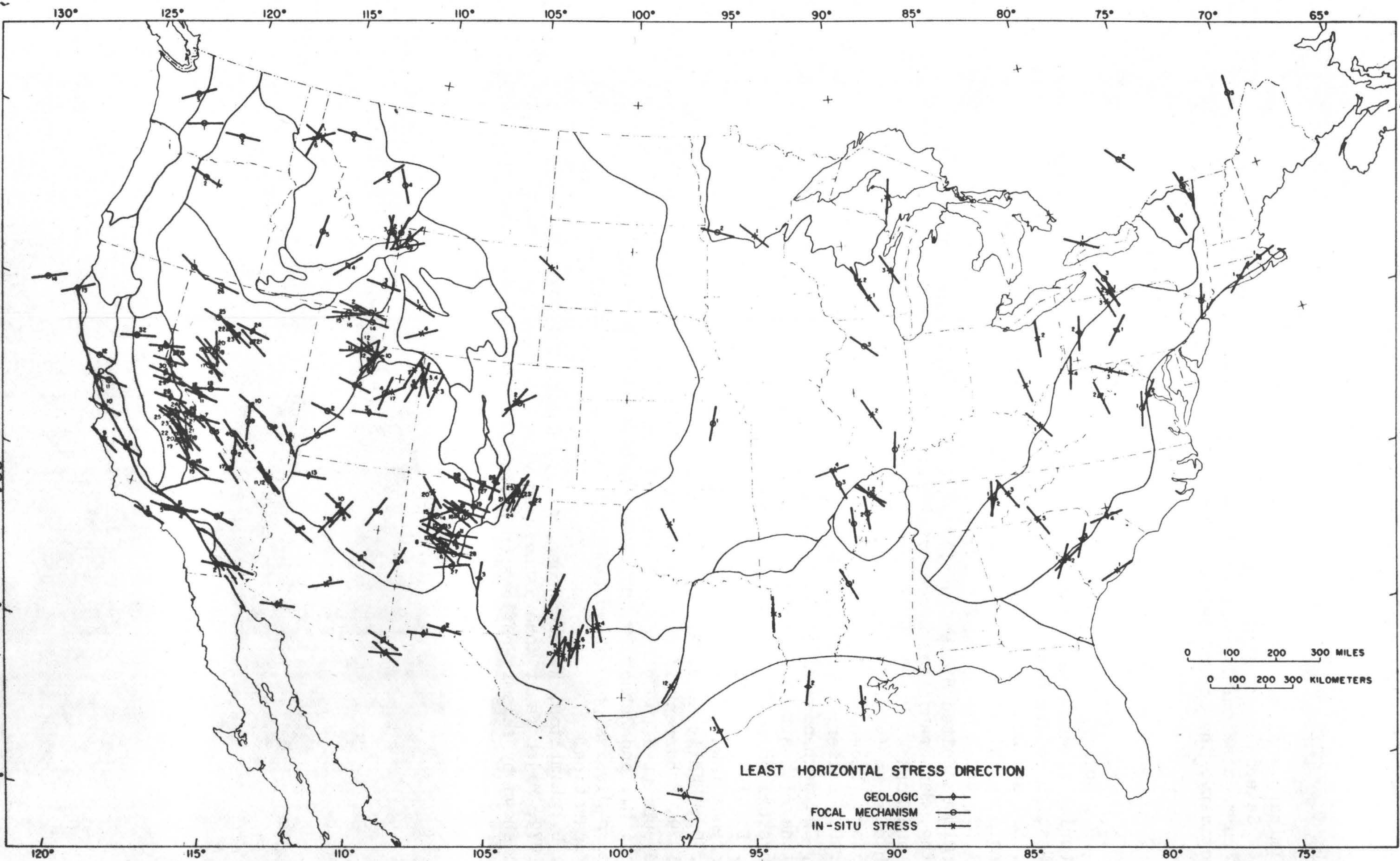

Figure 1: Least Horizontal Principal Stress Direction

SUMMARY REPORT

STUDIES OF CRUSTAL DEFORMATION PATTERNS OF AN ACTIVE FAULT: PIÑON FLAT OBSERVATORY

USGS USDI-14-08-0001-17764

by

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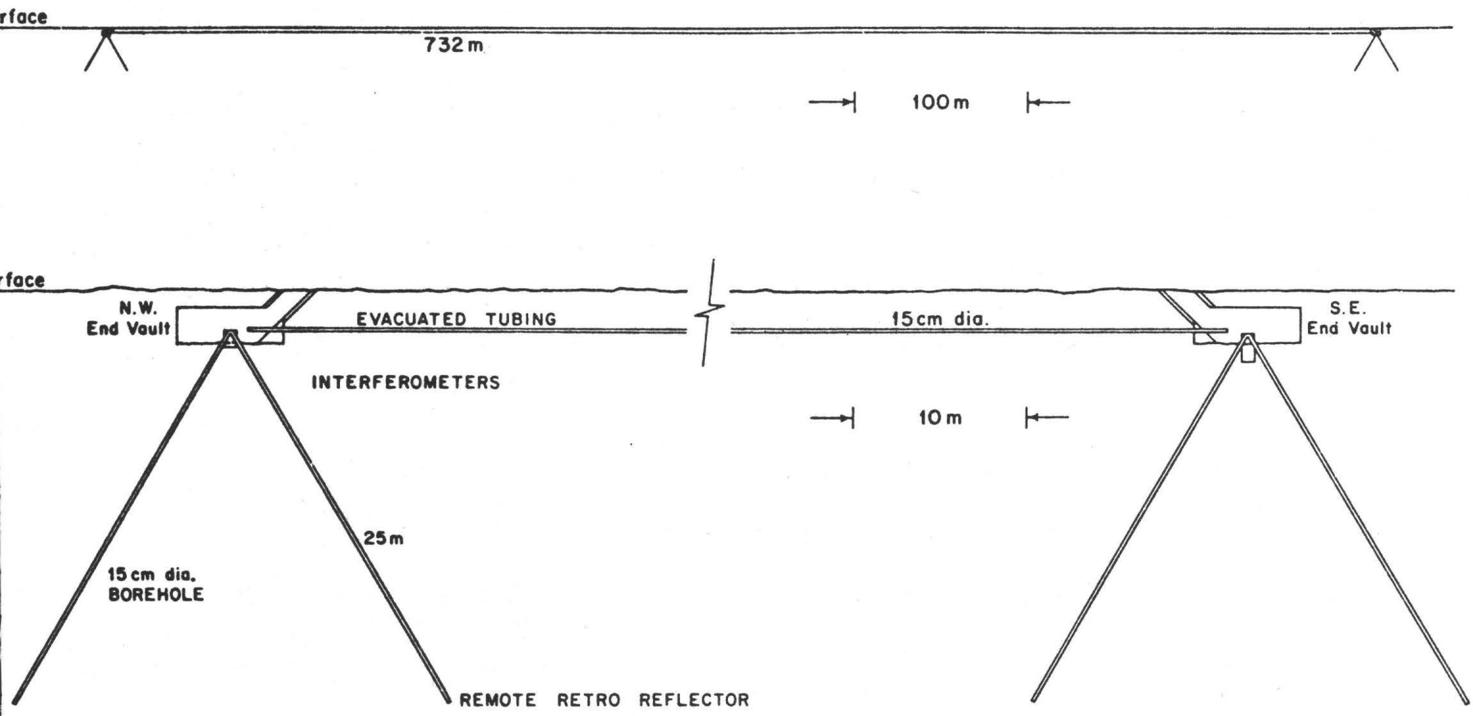
Comparisons between the strain rates observed at Piñon Flat Observatory (PFO) and those observed by geodetic techniques over a grid that encompasses the observatory show that there is general agreement between the results of these two methods. Thus, we believe we are measuring the true secular crustal strain rates. It must be noted that variations in the individual line lengths were averaged to produce the array strain rates in the geodetic technique. Similarly, there are fluctuations about the linear trends of the Piñon Flat strainmeter records. These excursions of the observed strains about these linear trends, having amplitudes on the order of 5×10^{-7} and periods typical of months, are artifacts associated and coincident with large rainfalls. However, these measurements put upper limits on the temporal fluctuations of the crustal strains about their linear trends. What is important to note, is that these upper bounds are themselves at the limits of resolution of geodetic techniques, both standard geodimeter surveys (Savage and Prescott, 1973) and multi-color laser ranging (Slater, 1978). If, indeed, the pattern of secular deformation in southern California is uniformly on the order of a few parts in 10^{-7} per year, as Savage (1978) observes, we should anticipate episodic behavior at levels smaller than this. Thus, we must use other than geodetic techniques in order to observe such behavior.

The program of strain measurements at PFO has provided consistent upper limits to the spectrum of crustal deformations occurring in this area. These strain measurements show noise levels over a wide period range (years to seconds) that are lower than those observed elsewhere by the same technique or by other techniques. However, in the strain signals there are still artifacts that we know are unrelated to the true crustal deformation. We believe the major source of noise is the local motions of the end piers, motions that are occurring in the surface layers of the ground unrelated to motions at depth. Ideally one would like to measure the crustal strain at some depth where the rocks are competent and relatively unaffected by surface conditions. To accomplish this, we have designed and built what we call an "optical anchor."

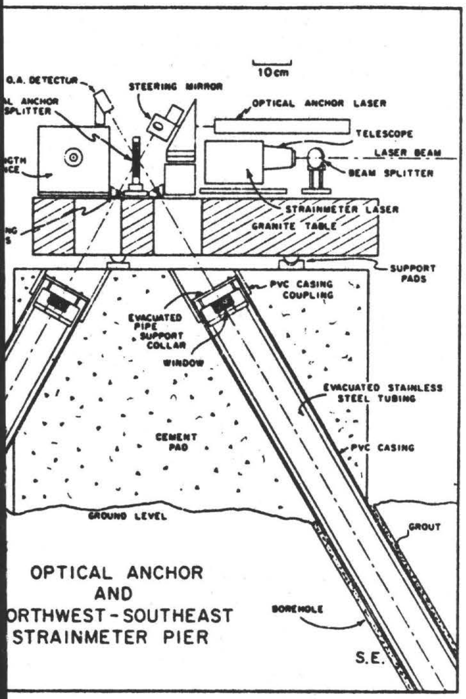
We have installed the optical anchor on the northwest end of the northwest-southeast strainmeter. The overall scheme is illustrated in Figure 1. Two holes inclined at 30° to the vertical were drilled at the northwest end of the strainmeter, some 25 m into the subsurface granite. Examination of the drill tailings indicated that the material becomes competent at a depth of about 15 m. The holes were drilled in the plane of the strainmeter and intersected at a point slightly above the end piers. The driller managed to maintain the two holes to within 8 cm of a straight line along their 25 m length. Retroreflectors were grouted in the holes near the bottom and an equal arm Michelson interferometer constructed using these paths. If the end pier moves in a plane perpendicular to the strain measurement both arms of the optical anchoring system will change an equal amount and the interference pattern will not change. However, if the end pier moves out of this plane the displacement will produce both an artificial strain and a change in the fringe pattern of the equal arm interferometer. Thus the output of the optical anchoring system will be used to remove the near surface displacements from the strain records. The upper assembly details are displayed in Figure 2.

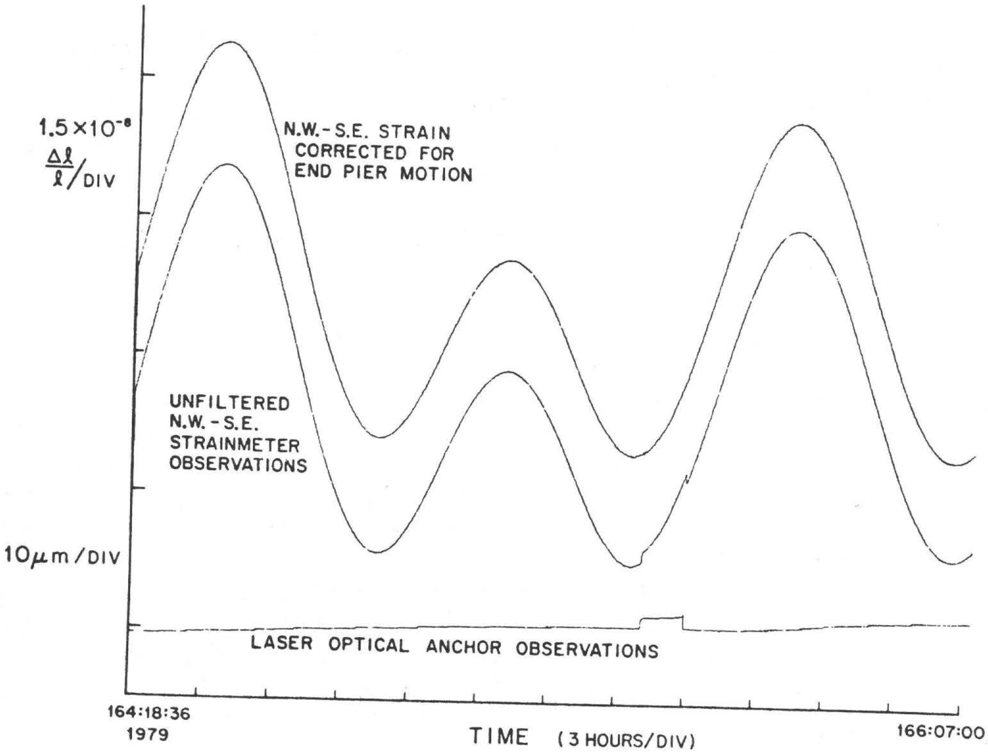
Operation of the optical anchor and the resumption of operation of the NW-SE strainmeter began in May 1979. Figure 3 shows a short section of data recorded by the two systems and the corrected strain observations. The resolution or least count of the optical anchor corresponds to a motion of the pier of 7.5×10^{-6} cm relative to the points at 25 m depth. The upward going pulse visible in the optical anchor observations and the NW-SE strainmeter observations is the result of deliberately parking a heavy vehicle over the strainmeter end vault.

The same problems that exist with near surface strain measurements also exist with tilt measurements. Tilt is, after all, just a different spatial derivative of the same basic crustal deformation. The instability of shallow borehole tiltmeters which is apparent in attempts to measure crustal deformations of the magnitude we know are occurring in southern California ($\sim 10^{-7}$/yr) has led us to a program of development of a long base fluid tiltmeter. Our program is basically a three step approach. First, we have built a relatively short (50 m) Michelson type instrument. The purpose of this installation is to evaluate our method of emplacing the end piers. Second, we will build alongside this--a 500 m instrument of the same type. The third step will be to convert the Michelson type instrumentation to a centered pressure transducer type instrument to widen its bandwidth and test that type of device.



Schematic of Optical Anchoring System





Tectonic Monitoring of the Solomon & New Hebrides Islands Regions

14-08-0001-17771

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The major technical objective of this programme is the installation of an array of permanent automatic stations for the measurement of magnetic field, strain and tilt in the New Hebrides Islands, the Solomon Islands and Eastern New Guinea. The array comprising eighteen stations spaced at intervals of not more than one hundred kilometers is designed to reliably capture any precursors which exist for shallow events of magnitude greater than 7 within the area, and has an event capture probability approaching one event (detected by two or more stations) every two years. In addition, shallow events in the magnitude range 6 to 7 (which occur at the rate of approximately five per year in the whole area) will be captured with 60% probability by two or more stations in the array. The capture probability for events smaller than 6 is very low. Failure to observe precursors for events larger than 7 in the array would also be considered to be of great significance to earthquake prediction research. It is unlikely that any large event in the area will be more than one or two source dimensions from two independent recording stations. The non-existence of precursors at this distance for any of the parameters under study would point to the need for a major re-evaluation of the feasibility of prediction of large events by such geophysical instrumentation.

The choice of this particular set of instruments for initial deployment is based on their specific productivity and wide current deployment in California and elsewhere. Other instruments and techniques are to be added to the array after the present initial deployment is complete. The remoteness of the sites and the low station density place very stringent requirements on station performance. Stations are designed for annual maintenance only. Normal data collection is via the GOES satellite system, with a reserve on site data store of day averages for all sensors in an EPROM storage module. Four types of data will be taken at each site (total magnetic field, tilt (2 sensors), strain (3 sensors), and environmental (rainfall, station performance parameters) allowing validation of the data set across the different sensor types. Each site is to be controlled by a microprocessor which will also be used for low order data processing prior to transmission.

Initial deployment will be made early in 1980 with twelve recording magnetometer stations. Fabrication of the other sensors is current. A detailed study of the seismicity of the study area has been completed to permit rational selection procedures for station locations. A preliminary magnetometer survey of the region has also been completed for site selection. No other data has been taken at this stage.

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Contract No. 14-08-0001-16745

DEEP-WELL MONITORING OF STRAIN-SENSITIVE PARAMETERS OVER THE GREATER SOUTHERN CALIFORNIA UPLIFT

Current research under this contract is summarized as follows:

1. Groundwater radon-Chemistry studies. A study of the chemistry of groundwater collected for radon analysis is being carried out with two goals: (a) to determine if major element chemistry may act as an earthquake precursor and (b) to search for simultaneous changes in chemistry and radon-222.

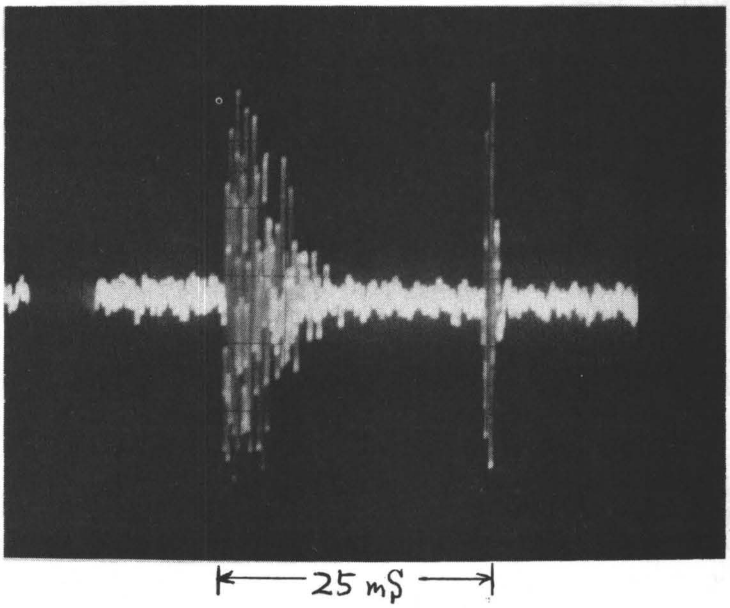
During this report period, a major earthquake occurred off Malibu on January 1, 1979, ∿ 20 km south of the Seminole Hot Springs research site. On October 12, 1978 and November 8, 1978, there were abnormally high radon levels of two and four times normal recorded at this site. There was no concomitant changes in major element chemistry. One problem in assessing these data is the weekly sampling rate. This problem should be corrected with the new USC continuous radon sampler now undergoing testing.

2. Acoustic Emissions. Field research in acoustic emission detection has been concentrated at two sites, the Del Sur and Skelton boreholes (∿ 10 km and 40 km northwest of Palmdale, respectively). We have recorded many events greater than 1 kHz at both sites. Thus far, frequency of events is between five and fifteen per day.

Figure 1 shows a typical sequence at the Skelton site. Each signal is usually a single burst lasting ∿ 10 ms. Occasionally, high frequency signals are accompanied by low frequency background. Figure 1a appears very similar to a greatly scaled-down earthquake. We have coined a name for these events -- nannoearthquakes. We are continuing research into the frequency of the events and whether they correlate with nearby earthquakes.

3. Air Gun Project. We have recently completed a refraction survey of the Del Sur borehole area. A sample of the refraction profile is shown in Figure 2. Numerous arrivals are evident. Shown on Figure 2 are the travel time curves for P and S waves observed by Hileman for the Galway Lake area and the Mojave desert. On the basis of our refraction line uphole survey at Del Sur (Figure 3) and Hileman's model, we have determined that S waves are observed over our borehole array. We will monitor these arrivals for travel time variation.

In an attempt to model our previous travel time observations and prepare for the current observation set planned, we have completed the analysis of a visco-elastic halfspace whose constitutive relationships are given by O'Connell and Budiansky (1974). The purpose of the model was to study the effects of dislocations in highly fractured rocks containing pore fluids that may diffuse from crack to crack. In our modeling we have found that dynamic equations of motion for such a medium have short time constants for the relaxation of viscous strain fields (order of minutes). Thus, diffusion theory is necessary for modeling pore pressure change related velocity anomalies. We are proceeding on calculations of such models.



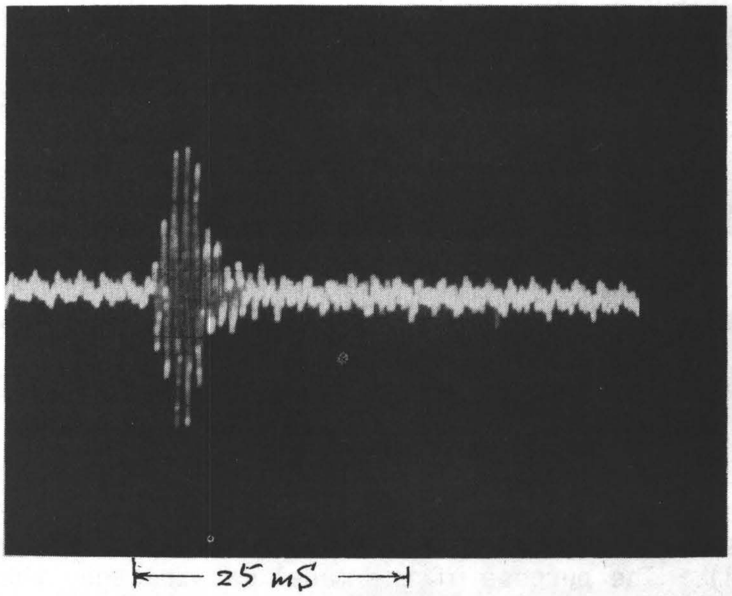


Figure 1a (top) and b (bottom). Typical acoustic signals (nannoearthquakes) recorded at the Skelton site (∿ 3 km north of San Andreas near Lake Hughes).

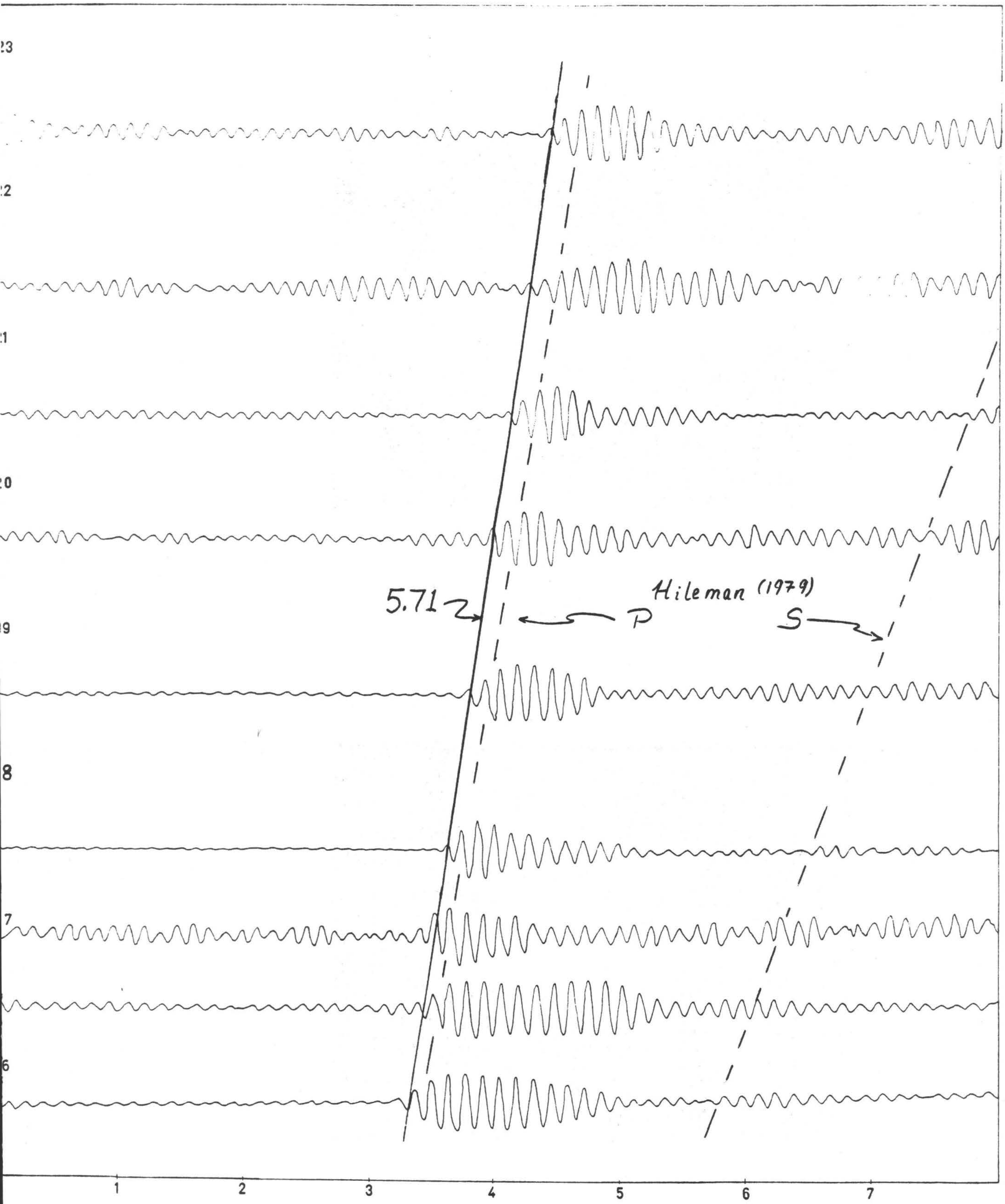


Figure 2. Surface refraction profile in the area of the Del Sur borehole. Note P and S times from Hileman.

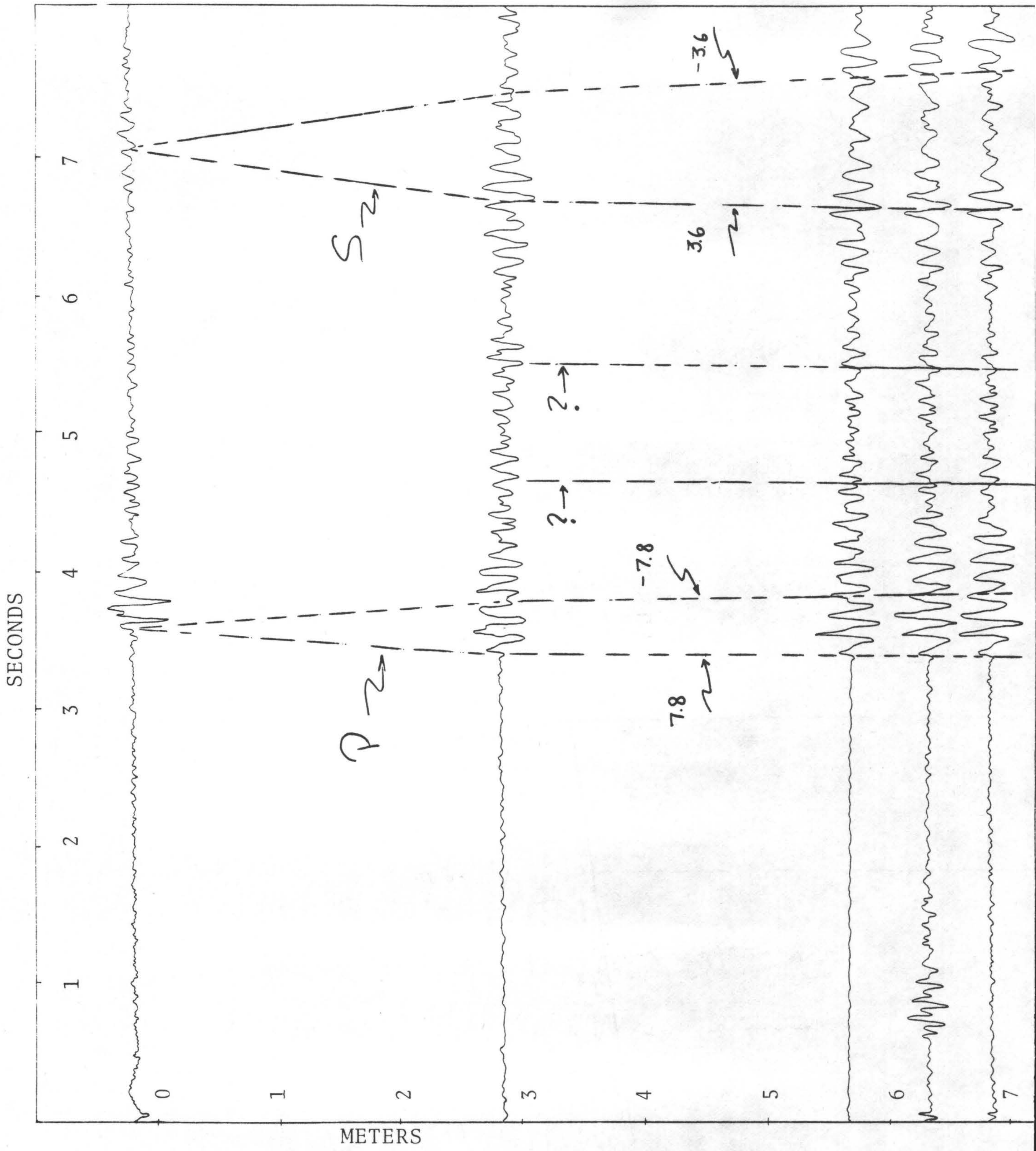


Figure 3. Uphole survey of Del Sur borehole with airgun source at Bouquet Reservoir. Depth in borehole is in hundreds of meters. Note P and S wave arrivals.

Prediction Monitoring and Evaluation

9920-02141

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Investigations

1. This project monitors and evaluates earthquake predictions from any source. Techniques have been established which can determine whether success in predicting earthquakes is due to skill or to chance. An extensive file of predictions now exists. Though predictions are no longer being evaluated, we continue to accumulate them both from non-scientists and scientists in the event the prediction of a particular event or predictions from a particular individual become an issue. Predictions are submmtted to this office or extracted from a variety of publications which are monitored.

Results

1. Since this program is a continuing project which monitors published predictions, final results in the usual sense cannot be expected although interim reports have been published in the past. Analysis has shown that non-scientist predictions are of no value.

2. The program created for the purpose of estimating the random probability of an earthquake in a region could be of some use to other projects. This program gives the probability of an earthquake for various geographic regions or locations, adjusted for size of quake and time span of interest, based on the Hypocentral Data File for the years 1963 through 1977 and assuming earthquakes of the observed sizes occur at the same rates. We have decided that the best way to extend the effective data time span to the length of the catalogues established for the U.S. is to use the data base used in the Seismic Risk Program.

3. The probability program could be expanded to calculate the changing probability of a quake as precursory phenomena are noted. The equations would be based on Bayes Law and require the random probability of an earthquake in a region and estimates of the probabilities that precursors precede earthquakes and non-earthquakes. We are exploring making estimates of these likelihoods. This would require input from survey scientists working more directly with such precursors.

Reports

No reports were published during this period.

Interpretation of Geophysical Data Premonitory of Earthquakes

8-0001-17687

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Investigations

1. We have analyzed leveling data for southern California to determine the mode of deformation resulting in the "Palmdale bulge."

2. We have studied magnetometer array data for central and southern California for evidence of earthquake precursors and coseismic magnetic changes.

3. We have continued research in two-dimensional seismic ray tracing.

Results

1. Successive leveling surveys on the profile Los Angeles-San Fernando-Saugus-Palmdale-Rosamond are plagued by benchmark instability and by systematic errors, including rod miscalibrations of the order of one part in 10^4. After deleting loose benchmarks (approximately 25% of all benchmarks) from the data set, we found that elevation changes between successive surveys were highly correlated with topography, both at short and long wavelengths (Figure 1). The sign of the correlation occasionally reversed where rod changes were made, implying that the correlation is due to rod miscalibrations. We separated both elevation changes and topography into long and short wavelength components, derived empirical rod correction factors from the short wavelength data (where tectonic effects seemed negligible), then applied these corrections to all data. Rod corrections could generally be determined to within ±20%, and were significant at the 1% confidence level. The corrected data (Figure 2) show no significant uplift of Palmdale with respect to Los Angeles from 1955 until 1968. Relative uplift in excess of 150 mm did occur between 1968 and late 1971; this was probably the result of the 1971 San Fernando earthquake.

2. Data from two UCLA and three USGS magnetometer stations within the aftershock zone of the Coyote Lake earthquakes show no precursory or coseismic magnetic anomalies greather than about 0.5 nT, although aftershocks as great as magnitude 4 occurred within 8 km of operating stations. A pair of USGS stations operating near the epicenter of the main shock (magnitude 5.4) show no precursory or coseismic changes to within 0.5 nT, even though one station was within 10 km of the epicenter. Apparently the seismomagnetic technique will only work for bigger earthquakes in more magnetic areas, if then.

/

3. We have developed an efficient two-dimensional ray tracing program based on the application of repeated Richardson's extrapolation to the solution of the Euler equations (the "bending method"). We are able to match the known ray path for the case $V = a + bz$ (where V is velocity, z is depth, and a and b are constants) to eight significant figures, although the estimated travel time is much less accurate. Current work addresses the problem of more accurately estimating the travel time.

Figure Captions

1. Plots of $\Delta h(x,t_o)$ and $\Delta^2 h(x,t) = \Delta h(x,t) - \Delta h(x,t_o)$ for profile Los Angeles-San Fernando-Saugus-Palmdale. Here Δh is the elevation difference in m between two successive benchmarks, x is distance along profile, and t is time in years; $t_o = 1965$. Dashed line is 10^{-4} Δh, solid line is $\Delta^2 h$. Negative correlations between $\Delta^2 h$ and Δh for 1955 and 1961 indicate that elevation differences were measured with a negative bias in those years compared to 1965. Note reversal of correlation in 1964 at Saugus, where rods were changed.

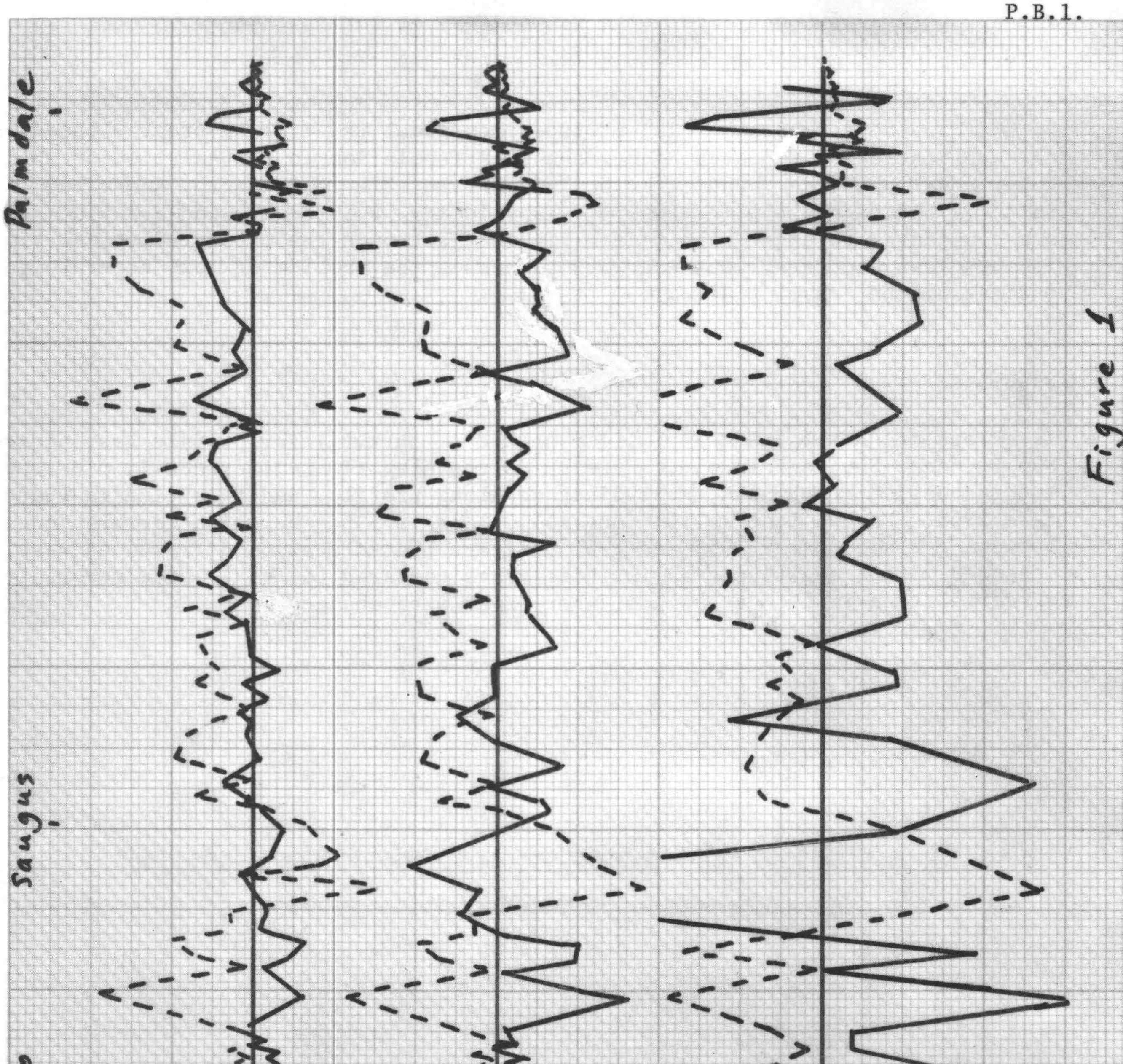
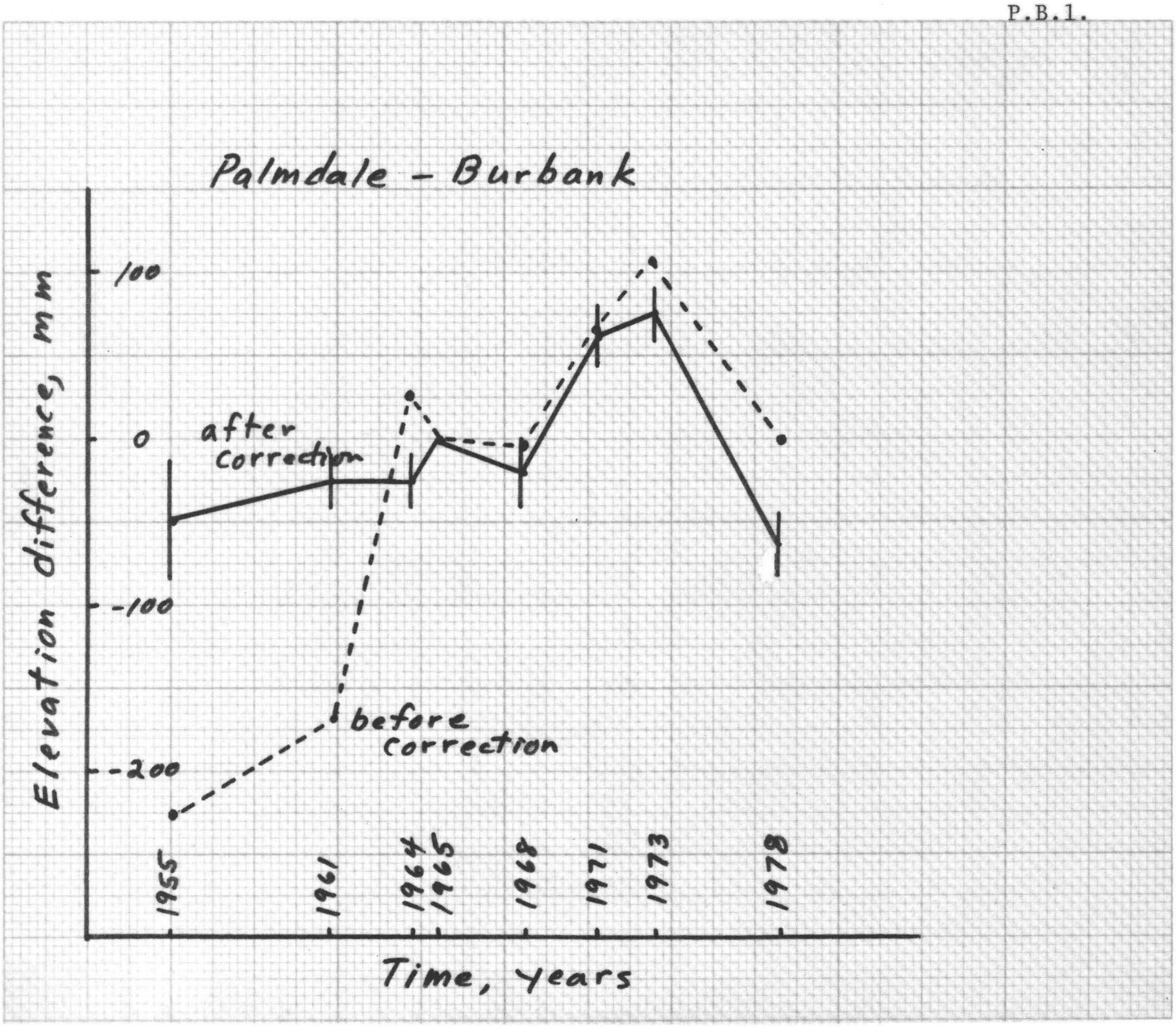
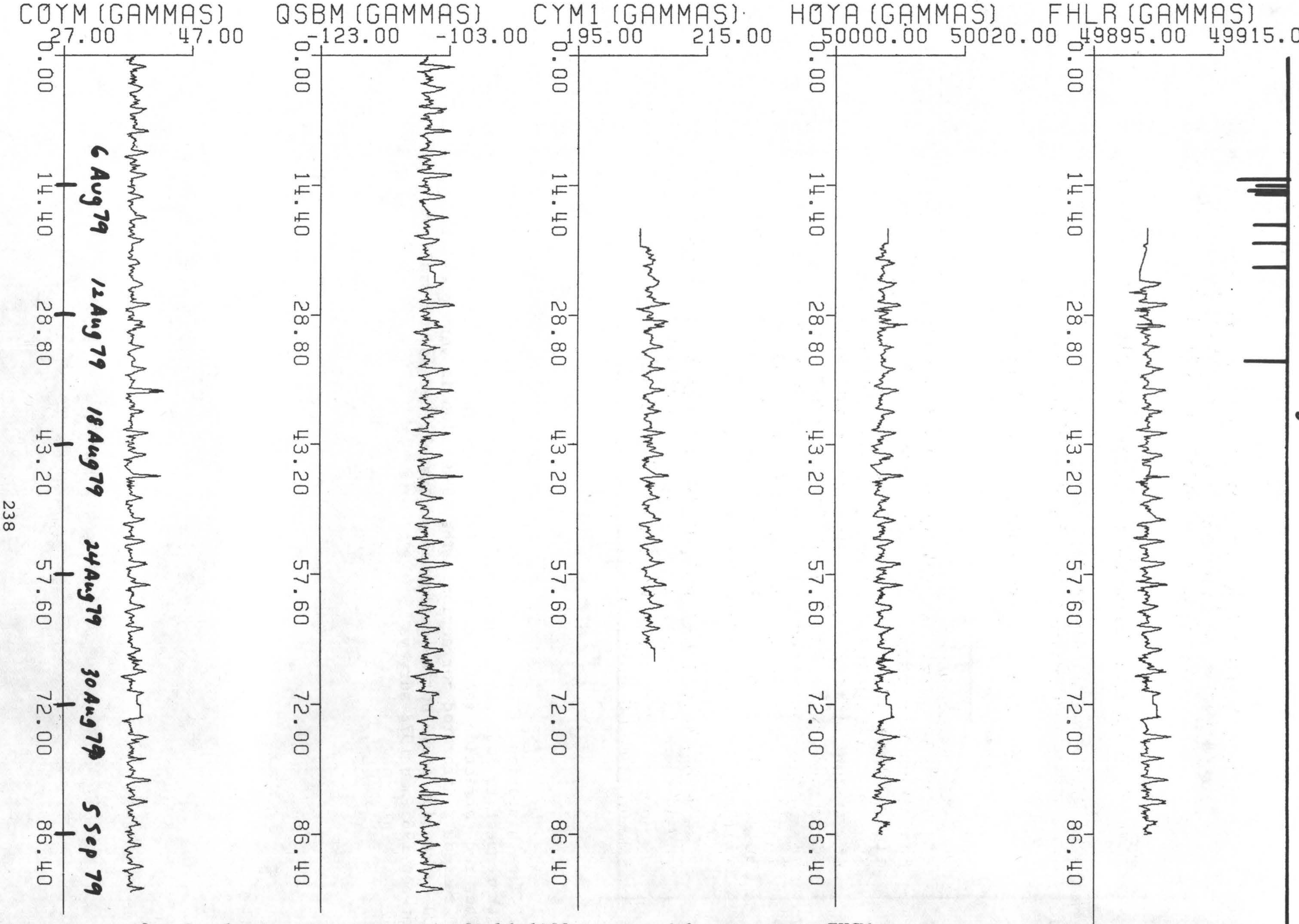

Los Angeles
San Fernando
Saugus
Palmdale
1964
1961
1955
5 mm
0
-5 mm

Figure 1



2. Time histories of elevation difference between Palmdale and Burbank, with respect to 1965 difference, before rod correction (dashed curve) and after rod correction (solid curve). Error bars indicate standard deviations of residuals after rod correction. The 1978 value is very preliminary; rod correction could not be estimated accurately because of small overlap between 1965 and 1978 surveys.



P.B.1.

3. One-hour average magnetic field differences with respect to EUCM. for 5 proton precession magnetometer in vicinity of Coyote Lake earthquake. Upper two curves are UCLA magnetometers; lower curves are USGS magnetometers. Occurrence times of the main shock and aftershocks greater than magnitude 3.5

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Seismicity and Earthquake Prediction Studies in Turkey

Summary of Semi-Annual Technical Report, August 1978 - January 1979
Contract No. 14-08-0001-16887

Principal Investigator: M. Nafi Toksöz

In the first six months of this project the efforts have been directed primarily toward the planning of the field installations. The sites of the permanent stations (Van and Hatay-Antep provinces) have been finalized. The deployment of the dense network at the western part of the North Anatolian Fault Zone has started. Four stations are currently operating. The remaining stations will be installed in June. The equipment (creepmeters, seismographs, water-level detectors) has been ordered. Field installations will be during June-August 1979.

The analysis of seismicity of the North Anatolian Fault Zone is continuing in two directions: (1) Space-time migration of earthquakes, and (2) Study of swarms as possible precursors of earthquakes.

Seismic Studies for Earthquake Prediction

9930-01727

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Investigations

The objectives of this project are to develop, by seismological techniques, an understanding of earthquake mechanics and the physical properties of fault zones leading to the prediction of potentially damaging earthquakes. During the reporting period, project effort was directed toward investigations of spatial and temporal variation in stress orientation and the redistribution of stress on a regional scale following moderate-to-large earthquakes. Sympathetic seismicity--the possible triggering of events well outside the aftershock area--has been examined following several moderate-to-large earthquakes in northern California and Nevada. Papers describing studies of the 1978 earthquake sequence near Thessaloniki, Greece; microearthquakes in the New Madrid seismic zone at Reelfoot Lake, Tennessee; and the Willits, California aftershock sequence were drafted. During the reporting period an investigation of the seismic history of the Calaveras fault zone in the vicinity of the 1979 Coyote Lake earthquake was begun, and Dr. Bufe participated in the U.S.-U.S.S.R. cooperative program, visiting Nurek Dam and the earthquake research center at Garm, U.S.S.R.

Results

Sympathetic Seismicity

Following the failure of a portion of a fault system in a moderate or large earthquake, regional stress redistribution should occur during the period of aftershocks and aseismic afterslip. This will result in an increased ratio of shear-to-normal stress on some sections of the fault system, a decreased ratio on others. Thus the regional seismicity pattern outside the immediate aftershock region during this period may be useful in identifying zones of increased stress where future moderate or large earthquakes are likely to occur. The phenomenon of sympathetical seismicity (in this case, "distant aftershocks") has been studied following the 1952 Kern County earthquake ($M = 7.7$) and seven smaller (5.5 to 6.0) earthquakes in northern and central California since 1952. Although it is very difficult to establish that the regional seismicity is influenced by the occurrence of the large events, it can be shown that the "distant aftershocks" tend to occur on fault segments which later experience moderate earthquakes or anomalous crustal deformation. In a sense the "distant aftershocks" might be considered prematurely triggered foreshocks.

Conventional aftershock activity ($M \geq 5$) occurred in the vicinity of the 1952 Kern County earthquake, subsiding noticeably 11 days after the main shock. Outside the immediate aftershock region, three small swarms occurred along a line extending ESE from Santa Cruz Island to San Gorgenio Mountain--across the region of the later southern California uplift--during the week following the earthquake. No earthquakes were located in northern California for 9 days following the Kern County event. On the 10th and 11th days, single shocks occurred near Mount Hamilton and near Concord. Moderate earthquakes ($M = 5.5$ and 5.4) occurred near the epicenters of these events three years later.

Seismicity was also examined for 5-day periods following seven magnitude 5.5 to 6.0 events in central and northern California, exclusive of Cape Mendocino. The main shocks occurred in 1952, 1955, 1961, 1966, 1969, 1975, and 1979. The vicinity of the 1979 Coyote Lake earthquake showed activity following both the 1969 and 1975 earthquakes, and thus could have been targeted as a likely zone for a moderate-to-large earthquake. The 1961 and 1966 events were also preceded, within a decade, by possible cases of triggered foreshocks.

Reports

Bakun, W. H., Stewart, R. M., Bufe, C. G., and Marks, S. M., 1979, Implication of seismicity for failure of a portion of the San Andreas fault: Seismological Society of America Bulletin, v. 69 (in press).

Bufe, C. G., Bakun, W. H., and McEvilly, T. V., 1979, Historic seismic activity and the 1979 Coyote Lake sequence (abs.): EOS, American Geophysical Union Transactions, v. 60 (in press).

Kodama, K. P., and Bufe, C. G., 1979, Foreshock occurrence in central California: Earthquake Notes (in press)

Peppin, W. A., and Bufe, C. G., 1979, Induced (?) vs natural earthquakes: Search for a seismic discriminant: Seismological Society of America Bulletin, v. 69 (in press).

Warren, D. H., 1979, A study of fault plane mechanisms preceding the Thanksgiving Day, 1974 earthquake at Hollister, California: Geophysical Research Letters, v. 6, p. 633-636.

Remote Monitoring of Source Parameters for Seismic Precursors

9920-02383

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Investigations

1. We designed and implemented a technique of processing (SRO) digital data. The processed output (e.g., deconvolved displacement, velocity or velocity-squared) would be in a convenient form for characterizing pulse shapes and for extracting source parameters such as stress drop, rupture geometry, rupture direction, and radiated energy.

2. We are using the program described in (1) to analyze the rupture characteristics of three deep earthquakes in three different island arcs. The parameters extracted from body phases, which were well separated in time for these deep earthquakes, should provide the insight required to examine shallow earthquakes where one must account for the surface reflected wave forms that are not well separated in time.

3. We are pursuing a body wave analysis of the St. Elias, Alaska earthquake of February 28, 1979 using the SRO digital data. The earthquake appears to have been a multiple rupture. The description of the rupture process that we obtain should help in evaluating the effectiveness of a standardized and digitally recording network of seismographs as a remote means of nonitoring source parameters.

4. We are currently examining a sequence of earthquakes associated with a shallow main shock in the Adak region of the Aleutians. By studying the records of displacement and velocity, we hope to discern a pattern of stress drop or rupture propagation in this sequence of earthquakes which could have been used to predict the main shock.

Results

1. A computer program has been developed that deconvolves the instrument response from SRO digital data by combining long and short period seismograms to yield broad-band displacement records. The same program also yields in the time domain broad-band velocity and velocity-squared seismograms. The stability and high quality of the

SRO digital data preserves the high-frequency spectral-phase information that is necessary for the accurate determination of pulse characteristics.

2. Using the program above, we studied three deep earthquakes. It turns out that the azimuthal distribution of the limited number (8) of SRO stations which recorded the events enabled us to obtain a number of source parameters and to constrain the source geometry. Furthermore, the deconvolved depth phases provided fiducial arrival times that were used to constrain the depth of the event and there is evidence of multiple rupturing for one of the earthquakes.

3. A preliminary examination of digitally recorded body phases generated by the St. Elias earthquake of February 28, 1979 indicates that the event was a multiple rupture, consisting of at least 3 sub-events.

Reports

Choy, G.L., D. Harvey, and J. Boatwright. Modelling the rupture characteristics of deep earthquakes. To be presented at the annual meeting of the AGU, San Francisco, California, December, 1979.

Pre- and Post-Earthquake Seismic Phenomenon Associated with the November 25, 1975 Hawaii Earthquake

14-08-0001-G-363

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May 1979

Investigations

1. The distribution, time variations, and focal mechanisms of pre-shocks and aftershocks of the November 29, 1975 Hawaii (Kalapana) earthquake are investigated. Understanding of the basic stress system giving rise to the earthquake as well as the primary mechanism of the main shock is sought. Preliminary to calculating locations of large numbers of aftershocks, crustal structure was investigated by inversion of earthquake and explosion P wave arrival times.

Results

1. Inversion work indicates that there is a low velocity layer or zone (LVL) at the base of the crust beneath Hawaii. Calculated depths of aftershock hypocenters and general regional earthquakes reveal that the maximum depth of crustal earthquakes is the top of the low velocity layer. This result is not model dependent in that several significantly different velocity models poduce the same basic effect. Scattered earthquakes are also located in the upper mantle to depths of 40 or more kilometers, particularly beneath Kilauea volcano.

2. The results of a detailed focal mechanism study of fore- and aftershocks of the Kalapana earthquake are in general agreement with a model of southeastward compression of the south flank of Kilauea volcano, presumably by magma injection along the principal rift zones. Immediately following the mainshock, the evidence suggests a complex period of stress readjustment.

3. Aftershocks distribute over a volume of the south flank crust and do not directly reveal the mainshock slip surface. Furthermore, the aftershock volume is much too small to contain the rupture area necessary for the magnitude 7.2 mainshock.

4. The focal mechanism calculated for the mainshock from teleseismic data and corroborated by modeling of the tsunami data, (Ando, in press), indicates major rupture on a low angle

or horizontal surface extending southward and well seaward of the southeast coastline of the island. On the other hand, the focal mechanism for the mainshock from the local island network, calculated using monotonically increasing velocity models (without a basal LVL), do not agree with teleseismic results. However, recalculated focal mechanisms from local data using the derived velocity model with LVL, agrees substantially with the teleseismic results. This is viewed as: a) providing confirmation and support for the low angle mechanism model, and b) providing independent confirmation of the validity of the crustal model with LVL. To reconcile the two focal mechanisms, an LVL is required to increase the crossover distance of certain key station observations at the local network. The crustal model does not affect the teleseismic interpretation.

5. A model of the mainshock process which is consistent with the available data is as follows: a) Stress accumulates in the crust of the south flank of Kilauea by repeated injection of magma along the rift zones to nearly the depth of the base of the crust. This process is documented by geodetic strain measurements. It is likely that non-catastrophic slip or creep occurs on the weak zone at the base of the crust as the process of strain and stress buildup proceeds. b) Catastrophic release occurs by slippage on a nearly horizontal plane within the comparatively weak LVL at the base of the crust. The properties of this zone are such that aftershock production is suppressed on the main slip surface, stress levels being apparently too low. Instead, aftershocks are produced in the highly stressed and inhomogeneous volume of crust adjacent to the rift zone which responds by brittle fracture after having undergone sudden reduction of stress. c) The result is a major lateral movement of the large block of crust which constitutes the south flank of Kilauea volcano and the subjacent oceanic crust. The surficial evidence for slumping and normal faulting is viewed as being a superficial response to the major displacement. A weak layer at depth is an essential component of this process and its existence could well be the factor controlling whether or not such large scale lateral movement, as in common in the Hawaiian islands, occurs on volcanic islands. Prediction of an impending large earthquake might be accomplished by carefully planned continuous monitoring of the surface strain field.

<u>Reports</u>

Crosson, R.S., and R.Y. Koyanagi, 1979, Seismic velocity structure below the island of Hawaii from local earthquake data, in press, J. Geophys. Res.

Rodgers, D.B., 1978, The Hawaii earthquake of November 29, 1975: Focal mechanisms of associated events, M.S. Thesis, University of Washington.

Pre- and Post-Earthquake Seismic Phenomenon Associated with the November 25, 1975 Hawaii Earthquake

14-08-0001-G-363

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Investigations

1. Primary phase readings were obtained for over 4000 earthquakes recorded on the Hawaii (USGS) network from about mid-1973 through 1976, including the main shock and principal aftershocks of the November 29, 1975, magnitude 7.1, Kalapana earthquake. Objectives of research include: a) determination of a new crustal model for improved location of aftershocks and better understanding of the relationship between structure and tectonics; b) location and interpretation of the spatial and temporal characteristics of aftershocks; c) identification and evaluation of precursory anomalies if any; d) determination of focal mechanisms of foreshocks and aftershocks for tectonic interpretation; and e) understanding of the tectonic framework of the south flank of Kilauea Volcano.

Results

1. A Hawaii crustal velocity model was developed by inversion of earthquake and explosion P arrival data acquired by the Hawaii seismograph network prior to November, 1975. The model, derived at an early stage of this investigation, substantially improves residuals in routine location processing. Furthermore, a striking result of the model is a low velocity layer (LVL) at the base of the oceanic crust from about 9 to 12 km depths. We now believe that the LVL may have substantial importance in tectonic interpretation.

2. Aftershock locations distribute in a complex volumetric pattern over the landward part of the south flank, mostly west of the main shock epicenter, indicating that the central part of the south flank of Kilauea was involved in the rupture process. Although there is spatial clustering in the aftershock zone, contrary to usual experience, no main slip plane is defined. Aftershocks appear to be occurring in response to a major change of stress in the crustal block south of Kilauea's rift zones, not to details of post-rupture readjustment on the main slip surface.

3. P and T axes are stable in orientation from 1973 onward. Although data are relatively poorer in quality, mechanisms are being determined back to 1970 to investigate the possibility of precursory stress field rotation.

4. Interpretation of focal mechanisms plays a major role in understanding the tectonics of the south flank of Kilauea. In order to reconcile teleseismically and locally determined focal mechanisms, an LVL model or a model with an anomalously thick crust are required. This result lends indirect support to the LVL model and allows us to correctly determine many individual mechanisms for pre- and post-main shock earthquakes. Substantial evidence indicates that the main shock rupture surface is nearly horizontal and in the lower crust. The areal extent of the surface is about 40 km EW and 40 km or more extending southward from the east rift zone. Few, if any, aftershocks lie on the main rupture surface. The slip direction is normal to the lower east rift zone of Kilauea, about 20 degrees east of south. Focal mechanisms for 24 south flank earthquakes which were felt in 1974 were determined using several models for comparison purposes. The LVL model produced remarkably consistent mechanisms for most of these events, with solutions virtually identical to the later November 29th earthquake. These results are interpreted to lend support to the LVL model and to indicate a consistent tectonic pattern throughout the south flank. Figure 1 shows the slip vector directions for these events, indicating that this process is fundamentally related to the crustal extension documented by surface geodetic measurements. We have also determined that numerous aftershocks of the November 29 earthquake have mechanisms similar to the mainshock mechanism.

5. The entire south flank of Kilauea Volcano to a depth of about 10 km is apparently acting as a relatively coherent crustal block, being wedged seaward in a SE direction by forceful intrusion of magma along the rift zones. A weak, low stress zone at depth, corresponding to the detected LVL, is the decoupling zone where accommodation of this movement occurs. Periodic catastrophic failure occurs when stress builds up in a large volume of the crustal block south of the rift zones. It is postulated that, in fact, the Kilauea type of crustal rifting requires the existence of a weak "lubricating" layer at depth.

Reports

Crosson, R.S., and R.Y. Koyanagi, 1979, Seismic velocity structure below the island of Hawaii from local earthquake data, J. Geophys. Res., 84, 2331-2342.

Crosson, R.S., and E.T. Endo, 1979, The effect of structure models on focal mechanisms of earthquakes related to the November 29, 1975 Kalapana, Hawaii earthquake, (abstr.), AGU Fall Meeting.

Rodgers, D.B., 1978, The Hawaii earthquake of November 29, 1975: Focal mechanisms of associated events, M.S. Thesis, University of Washington.

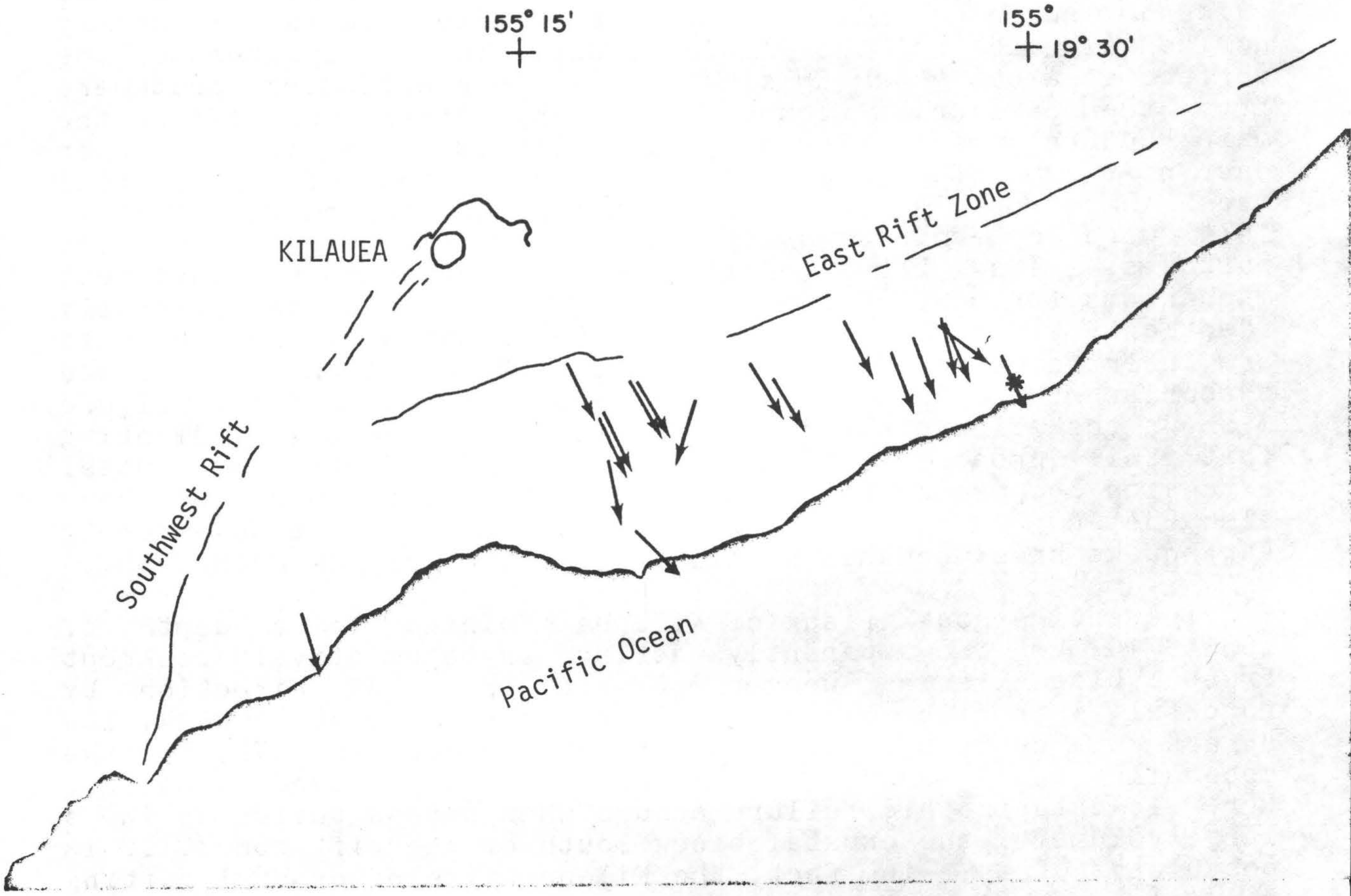

Fig. 1. South flank region of Kilauea Volcano, Hawaii, showing slip directions for number of 1974 felt earthquakes as determined from focal mechanism solutions. The symbol (*) refers to the November 29th main shock.

Teleseismic Search for Earthquake Precursors

9920-02142

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Investigations

1. J. Dewey spent two months in the USSR at the Department of Computational Geophysics, Institute of Physics of the Earth, Academy of Sciences, studying their use of the Bongard pattern recognition algorithm and their methods of long-range prediction of earthquakes based on seismicity patterns.

We are planning to use the Bongard algorithm to extend our study of the last year and a half, which was devoted to the seismicity associated with four large subduction zone earthquakes, three in Peru and one in the Adak region of the Aleutian Islands. The specific results for these earthquakes have been given in volumes VII and VIII of the Summaries of Technical Reports. In brief, among the characteristics of precursory seismicity that have been proposed, our data give most support to the hypothesis that teleseismically-recorded activity often increases immediately adjacent (within 10 km) to the future main shock source region several years prior to the large earthquake. However, it is quite clear that some large subduction zone earthquakes have not been preceded by an extended period of increased moderate earthquake activity near their focal regions and that some increases in moderate-magnitude seismicty in subduction zones are not followed by large earthquakes. We will use the Bongard algorithm to analyse other effects (such as regional tectonic environment and other measures of seismicity besides the level of moderate earthquake activity) in all combinations of one, two, and three effects, to see if there is a characteristic suite of effects that indicates that a moderate earthquake in a subduction zone is likely to be followed by a large earthquake.

2. J. Dewey and W. Spence completed their study of seismic gaps and source zones of recent large earthquakes in coastal Peru.

Results:

The results bearing on the objective of the project, which is to recognize patterns of teleseismically-recorded seismicity that may be used to predict strong earthquakes, have been reported in earlier semi-annual reports.

A new result bears on the mechanism by which stresses are generated within plate interiors in subduction zones. The disastrous Peruvian earthquake of May 31, 1970 was a normal fault earthquake, or, at least, the initial rupture of the earthquake occurred as normal faulting, apparently within the Nazca plate. Stauder (JGR, 80, 1053-1064) and Isacks and Barazangi (Maurice Ewing Series, 1, 99-114) reported that the focal mechanisms of many of the aftershocks involved reverse faulting, also within the Nazca plate. We relocated the earthquakes of the sequence and found that the 130 km long aftershock zone comprised two clusters at the same depth and separated from each other by a zone, 40 km in length along the trend of the Benioff zone, in which there were no teleseismically-recorded aftershocks. Isacks and Barazangi (1977) characterized the aftershock focal mechanisms as "down-dip compression" or "down dip tension." For moderate aftershocks, their classification depended on whether first motions at selected stations were consistent with the well-determined, respectively down-dip compression or down-dip tension, focal mechanism of the larger earthquakes of the 1970 Peru sequence. Twenty-seven of their shocks lay in the southernmost of our two aftershock clusters, and 26 of these 27 were identified as down-dip compression shocks (B. Isacks, written communication, 1979). Of the four aftershocks they studied that occurred in the northernmost cluster, all are identified as down-dip tension shocks. The rapid change in focal mechanisms between our two aftershock clusters is similar to changes of focal mechanism with distance parallel to the strike of the Benioff zone observed for intermediate depth earthquakes in the Aleutian Islands (Engdahl and Scholz, Geophys. Res. Lett., 4 473-476). Such changes of focal mechanism parallel to the strike of the subduction zone evidently require models that consider the variations of stress and rheology in the subduction zone as functions of distance along strike. The characteristics of the aftershock sequence of the 1970 Peruvian earthquake would, in addition, support models that predict that the readjustment of stress following a large earthquake in a region of down-dip tension should favor the occurrence of aftershocks in a nearby region of down-dip compression.

Report: James W. Dewey and William Spence, "Seismic Gaps and Source Zones of Recent Large Earthquakes in Coastal Peru", accepted for publication in Pure and Applied Geophysics, in a special volume on seismic gaps.

Precursory strain/seismic anomaly studies on a strike-slip fault system

9930-02393

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Investigations

A. Deformation

1. Baseline measurements completed: a) 12 km long second order level line extending from the Kilauea leveling network. All turning points are nailed. In the region of deformation a 1 km long loop crosses the north end of mapped cracks. Every other turning point in the loop is tagged for identification. b) EDM measurements for a double braced quadilateral array that is located midway between ends of mapped ground cracks. c) EDM measurements for a 6.5 km long linear array parallel to the trend (0.5 km spacing between bench marks) of known faulting. d) Profile leveling for an example of a crack end that shows "screw-like" dislocation.

B. Seismic

1. Approximately 1000 copies of earthquake film records and hard copies of digitized seismic events have been collected for a focal mechanism study of the Kaoiki region and the south flank of Kilauea. Hard copies of select digitized seismic events clearly showing attenuation by a low Q zone beneath the summit caldera of Mauna Loa are also included in the data set. Special phase tapes were generated for the selected events using the Observatory Eclipse minicomputer system.
2. 1959-1977 Kaoiki earthquakes ($\sim$ 5000 events) were relocated using two different layered models.

C. Instrumentation

1. UHF radio and digital telemetry components installed for an Autonetics platform style tiltmeter emplaced in the MLO vault. Digital data is currently being recorded on magnetic tape and is routinely processed on a weekly basis by the Hawaiian Volcano Observatory staff.
2. A seismometer with extended high frequency response has been installed adjacent to a standard short period (1 Hz) located in the area of ground cracks.
3. A new automatic level (WILD NA2) tested for long base dry tilt measurements.
4. A standard temperature shield (IS-4) tested for air temperature measurements that are made during EDM work.

5. Recently developed temperature and pressure transducers also tested for possible application in improved pressure-temperature measurement techniques necessary for single beam EDM work.

Results

A. Deformation

1. None for deformation studies since all measurements made this past fiscal year are initial measurements.

B. Seismic

1. No new results to be presented at this time for seismic studies.

C. Instrumentation

1. Preliminary evaluation of the IS-4 radiation shield shows a mean difference of 1° centigrade with non-standard radiation shields being used routinely for EDM temperature measurements by the Hawaiian Volcano Observatory. The observations clearly show an existing problem in air temperature measurements made in EDM work. Additional work on the temperature radiation shield and temperature transducers pending delivery of a precision thermometry system.

2. Negative results for pressure transducer (LX1702). Device appears to be temperature sensitive and does not have the resolution necessary for routine EDM work.

Reports

Endo, E.T., J.S. Nakata, and R.S. Crosson, 1979, Focal mechanisms of crustal and mantle earthquakes beneath the Island of Hawaii, Abs., Hawaii Symposium on intraplate volcanism and submarine volcanism, p. 160.

Garm Source Mechanism Studies

9930-02100

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Investigations

Several questions of current interest to U.S. and Soviet investigators involved in joint studies for earthquake prediction 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 effects of propagation and near-station effects, do the estimates of the source spectrum at each station 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?

Results

During two trips by U.S. scientists to Garm, U.S.S.R., the telemetered seismic network set up in 1975 was rebuilt with new Soviet 3-component seismometers and USGS J-600 VCO-preamps. A modified tape loop recording system began operation and programs for a HP9845 computer were developed to locate and plot earthquake hypocenters. One field site was instrumented with a solar electric generator to test a possible solution to poor primary battery performance.

Approximately 150 local earthquakes recorded on Develocorder film in Garm between 1975 and 1978 were located using a BASIC version of HYPOINVERSE run on the HP8045 computer in Garm. This data set provides basic information on the nature of seismicity within the USGS Peter I Range array and establishes a basis for spectral and source mechanism studies.

Preliminary analysis of the seismicity pattern for the well-located events of the data set indicates: 1) shallow events (0-10 km) are scattered within a northeast-trending zone roughly corresponding to the crest of the Peter I Range; 3) deeper events (10-30 km) are confined to an area located just south and southeast of the crest of the Peter I Range; and 3) a clear gradation from shallow to deep events exists in northwest-southeast cross section.

Reports

The following articles were contained in Collected Soviet American Work in Earthquake Prediction, Book 1, Volume 2 (in Russian):

Kunakov, V. G., Maksimov, A. B., and Fischer, F. G.,
Development of the radio telemetry system located in Garm.

Wesson, R. L., Maksimov, A. B., Selivanov, M. V., and Fischer, F. G.
Regularity of azimuthal variations in corner frequency of local earthquakes.

Maksimov, A. B., Terasov, N. T., and Fischer, F. G.,
Structure of first motions of local earthquake body waves.

Microearthquake Data Analysis

9930-01173

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Investigations

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

2. The principal effort during the past six months has been devoted to a) refining numerical techniques for 3-dimensional seismic ray-tracing and b) studying the earthquake sequence of August 6, 1979 near Coyote Lake, California.

Results

Principal scientific results obtained are mainly from the study of the Coyote Lake earthquake. The August 6, 1979 earthquake (M 5.7 ± 0.2) was located about 1 km east of the Calaveras fault trace near Coyote Lake, at a depth of about 10 km. The spatial distribution of the aftershocks in the first 15 days and the focal mechanism of the main shock and selected aftershocks suggest that faulting took place primarily to the southeast of the main shock along a 25 km segment of the Calaveras fault zone at a depth of 4 to 12 km. The motion was right-lateral strike-slip along a nearly vertical fault plane. Discontinuous surface rupture was observed along a 14.4 km length of the recently active trace of the fault southeast of Coyote Lake, but no surface faulting was seen in the epicentral area. A maximum 5 mm fault offset was recorded near San Felipe Lake, about 16 km south of the main shock.

There was no priminent foreshock activity. The cumulative number of aftershocks (N) versus magnitude (M) could be described by the equation $\log N = 3.33 - 0.75\ M$, in the magnitude range between 1 and 3.5. The number and size of aftershocks appeared to be much less than that expected for a main shock of magnitude 5.7.

Reports

Lee, W. H. K., Herd, D. G., Cagnetti, V., Bakun, W. H., and Rapport, A., 1979, A preiminary study of the Coyote Lake earthquake of August 6, 1979 and its major aftershocks: U.S. Geological Open-File Report 79-1621.

Parkfield Prediction Experiment

9930-02098
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Investigations

Seismic data are being analyzed in conjunction with geodetic observations to develop the ability to predict the next magnitude 5.5 Parkfield earthquake. Our immediate goal is to use this information to build a strong working hypothesis against which slip and stress distribution along this segment of the San Andreas can be predicted and measured.

Results

We have relocated the earthquakes in the Parkfield area ($M \geq 2$) for 1969-78 and are compiling a near real-time (within three weeks) seismic catalog ($M \simeq 1$). We have also reexamined the seismic activity for the six months preceding the 1966 Parkfield earthquake and found that seismicity levels were five-to-ten-times lower than recent levels. We are presently in a relatively quiet period possibly similar to the period in 1974, 1976 and 1977 which preceded a magnitude 4-5 earthquake.

A paper with Dave Boore on the 1966 Parkfield earthquake has been completed in which it is shown that two discontinuities (a bend and an offset) controlled the points of initiation and termination of that rupture. These same two features play a large part in controlling the creep and seismic regime.

Several new alignment arrays and an array of invar wire strainmeters have been installed near the 1966 epicenter where measurement of established alignment arrays indicate a recent change in creep rate. We have assumed responsibility for Caltech's cluster of creep-, strain-, and tiltmeters at Gold Hill and are in the process of acquiring all local data records by telemetry. Creepmeters at Gold Hill and Slack Canyon have operated well and we were able to monitor a 1 mm creep event at Gold Hill in real time. The tiltmeters have not performed well due to thermal instability but field testing of a modified unit is underway.

Results of a gravity survey and geologic reconnaissance were used to resolve local structural complexities and to evaluate several rock units as possible sites for a pair of Sachs-Everson volumetric strainmeters. We intend to emplace the instruments at Gold Hill at a depth of 150-300 meters in hornblende quartz gabbro.

Reports

Mantis, C., Lindh, A., Savage, W., and Marks, S., 1979, Catalog of Oroville, California earthquakes - June 27, 1975 to July 31, 1976: U.S. Geological Survey Open-File Report 79-932.

Grosenbaugh, M., and Lindh, A., 1979, The spatial distribution of microseismicity near Parkfield, California: 1969-1976 (abs.): Earthquake Notes, v. 49, p. 41

Buhr, G., Motooka, C., Lindh, A., and Grosenbaugh, M., 1979, Seismicity prior to the Parkfield, California earthquake of June 28, 1966 (M_L=5.5) - A premonitory quiescence (?) (abs.): Earthquake Notes, v. 49, p. 40.

IN-SITU SEISMIC WAVE VELOCITY MONITORING

CONTRACT 14-08-0001-17645

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16 May 1979

REPORT SUMMARY
01 Oct 78-31 Mar 79

Work during this report period has been dominated by the preparation of new sites for the monitoring of travel-times and improvement of old sites, incorporating the knowledge on measurement precision gained thus far in the project. After several permitting problems, we have completed most of the planned sites at the Cienega Winery and Stone Canyon areas south of Hollister (a discussion of plans is included in the last technical report).

Site preparation has included:

1. Concrete pads at the source sites to which we bolt the vibrator's baseplate, in order to increase data precision and reproducibility.
2. Asphalt aprons around each concrete pad, to level the truck and control soil moisture under the pads.
3. Sub-water-table, bore-hole geophones at both source and receiver sites to correct for or eliminate the large near-surface seasonal variations in travel-time.
4. Construction of a concrete river crossing and improvement of the access road at the project's base of operations (USGS Stone Canyon compound), to make it an all-weather facility.

Monitoring of first arrivals has begun on the new paths at the Cienega Winery area, so far without the use of the concrete pads. Monitoring at the Stone Canyon area has been postponed until delivery of a bore-hole hydrophane package for the Stone Canyon deep well. In the meantime, routine monitoring of the first arrival has continued on the north-south path at the Winery area. Travel-times have increased significantly during the winter rainy season, following the seasonal pattern observed during the previous two winters on all paths.

Near-surface travel-time measurements carried out during 1978 at the Winery south vibrator site have now been analyzed, with illuminating results. The measurements were made with a hammer source and a bore-hole geophone well below the water-table. Variations of near-surface travel-time at the vibrator site account for most of the observed changes in travel-time on the north-south path. The remainder could well be due to variations immediately under the recording site. The near-surface variations are not entirely due to water-table position. Some other factor related to rainfall is also present - perhaps the moisture content of the soil at the surface. A new series of P- and S-wave down-hole measurements have begun at the Winery south site to investigate the mechanisms involved.

IN-SITU SEISMIC WAVE VELOCITY MONITORING

CONTRACT 14-08-0001-17645

TECHNICAL REPORT: 01 Apr - 30 Sep 1979

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R. Clymer

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TECHNICAL REPORT SUMMARY

As reported in the previous technical report, the UC vibrator, the seismic source for this project, was destroyed in a fire in April 1979, temporarily halting field work while a replacement vibrator was acquired. Work in the report period just past has focused 1) on refurbishing the vibrator donated to the University in August by Western Geophysical Company, and upgrading the recording system to render it compatible with the vibrator electronics, and 2) on a final analysis of the previous feasibility stage of the project.

Work on the vibrator truck and the vibrator hydraulics system has consisted of extensive repairing, overhauling, and testing. We expect that the end result will be a reasonably reliable field system. (Many lessons learned in operating the previous vibrator have been applied to the new machine at the outset.) The new system will be in the field in November 1979.

The vibrator control electronics represent up-to-date technology, and are expected to be more effective, reliable, and easy to maintain than the previous obsolete system. In addition to the sweep generator that is an integral part of the vibrator electronics, we have purchased a compatible sweep generator for the recording truck. The full field system of recording truck and vibrator can operate in two convenient modes:

1. In the "remote start" mode, the vibrator electronics are triggered by a code telemetered from the new recording truck sweep generator. Simultaneous ($\pm$ 0.25 msec) sweeps are generated in each truck, one to drive the vibrator, the other to be the correlation reference. The problems caused by continuous telemetry with marginal reception in mountainous terrain are avoided because the triggering system can operate under noise conditions that would preclude data telemetry.

2. In the "high precision" mode, the vibrator drive sweep is telemetered to the recording truck to serve as the correlation reference, and the $\pm$ 0.25 msec start-time jitter of the remote triggering system is avoided.

Great care has been taken to match the characteristics of the paths of all electrical signals to be compared.

Since the large scatter of past trave-time measurements was believed to be due to source instability in the form of vibrator rocking, an anti-oscillation system (patented by Litton Resources Systems) has been added to the new vibrator. In addition, similarity (i.e., system stability) tests will be much more diagnostic of source problems than in the past.

Routine field work is expected to resume by December 1, with regular monitoring planned for the present network and expansion as shown in Figure 1.

During the report period, a Ph.D. thesis on the study has been completed by R. Clymer. This thesis forms the bulk of the present report, summarizing results to date in the work. The abstract of the study follows.

HIGH-PRECISION TRAVEL-TIME MONITORING WITH SEISMIC REFLECTION TECHNIQUES

Richard Wayne Clymer

The search for earthquake prediction methods has been stimulated by a number of reports of significant variations of seismic travel-time before thrust- and normal faulting earthquakes, and frustrated by the general failure to detect such precursors before strike-slip earthquakes in California. The rationale for the study discussed here has been the premise that zones of anomalous velocity associated with strike-slip faulting may, in fact, exist, but that the involved volume and/or the velocity contrast may be too small for detection with the uncontrolled-source type of methods generally being used. The major goals of the study have been 1) to determine the feasibility of using controlled-source reflection and refraction methods for travel-time monitoring, and 2) to take a first look at the travel-time changes, if any, that may be detectable with such measurement techniques.

To these ends, travel-times have been repeatedly measured at sites in two areas south of Hollister, California, along the creeping zone of the San Andreas fault, using a single-channel VIBROSEIS* system with real-time on-site data processing. Events at 7 to 8 sec travel-time were monitored at sites about 7 km from the San Andreas fault in Bickmore Canyon, in both "short-term" experiments spanning a number of hours, and in a "long-term" series of measurements spanning about two years. Two associated contracted reflection

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* Registered trademark of Continental Oil Company.

surveys provided evidence that the late events monitored were deep crustal reflections. At the second area, centered approximately on the Cienega Winery, first arrivals were monitored on north-south and east-west paths immediately adjacent to the San Andreas fault, again producing a "long-term" record of about two years of measurements.

In Bickmore Canyon, the results of the first three "short-term" experiments, carried out over a 3-1/2 month period, showed large oscillations of travel-time of several msec peak-to-peak amplitude (about twice the peak-to-peak noise) synchronous and in phase with the measured gravity tide. This phase relationship is consistent with the premise that the travel-times were responding to tidal variations of normal strain in the direction of wave propagation. Surprisingly, during similar experiments over the following 8-1/2 months, no tidal response was detected, though there was no significant change in measurement resolution.

In the "long-term" measurement program in Bickmore Canyon, no variations in deep reflection travel-time were observed that could be associated with local earthquakes, perhaps due to the distance of the monitoring area from the San Andreas fault. However, significant variations (0.5 to 2.5 msec peak-to-peak) of first arrival travel-times were observed at the Winery area that may have been associated with a series of near-by earthquakes, and with a creep event.

Two major types of noise have been identified. First, scattering of the short-term data is believed to be due to source variations, and limits the measurement precision to about 0.01% of the travel-time for the deep reflections, and about 0.1% for the first arrivals. Secondly, the dominant features of the long-term data sets are persistent, rain-fall-related, seasonal oscillations in travel-time (of as much as 15 to 20 msec peak-to-peak), wavelet amplitude, and waveform. Bore-hole measurements show that these effects are due to changes in very near-surface conditions. The seasonal travel-time variations imply a measurement accuracy of about 0.2% for the deep reflections and about 1% for the first arrivals.

While these noise levels are disappointing, they can be reduced significantly by improved field procedures. Further experiments are planned that will test such procedures, and search more carefully for travel-time variations along this section of the San Andreas fault.

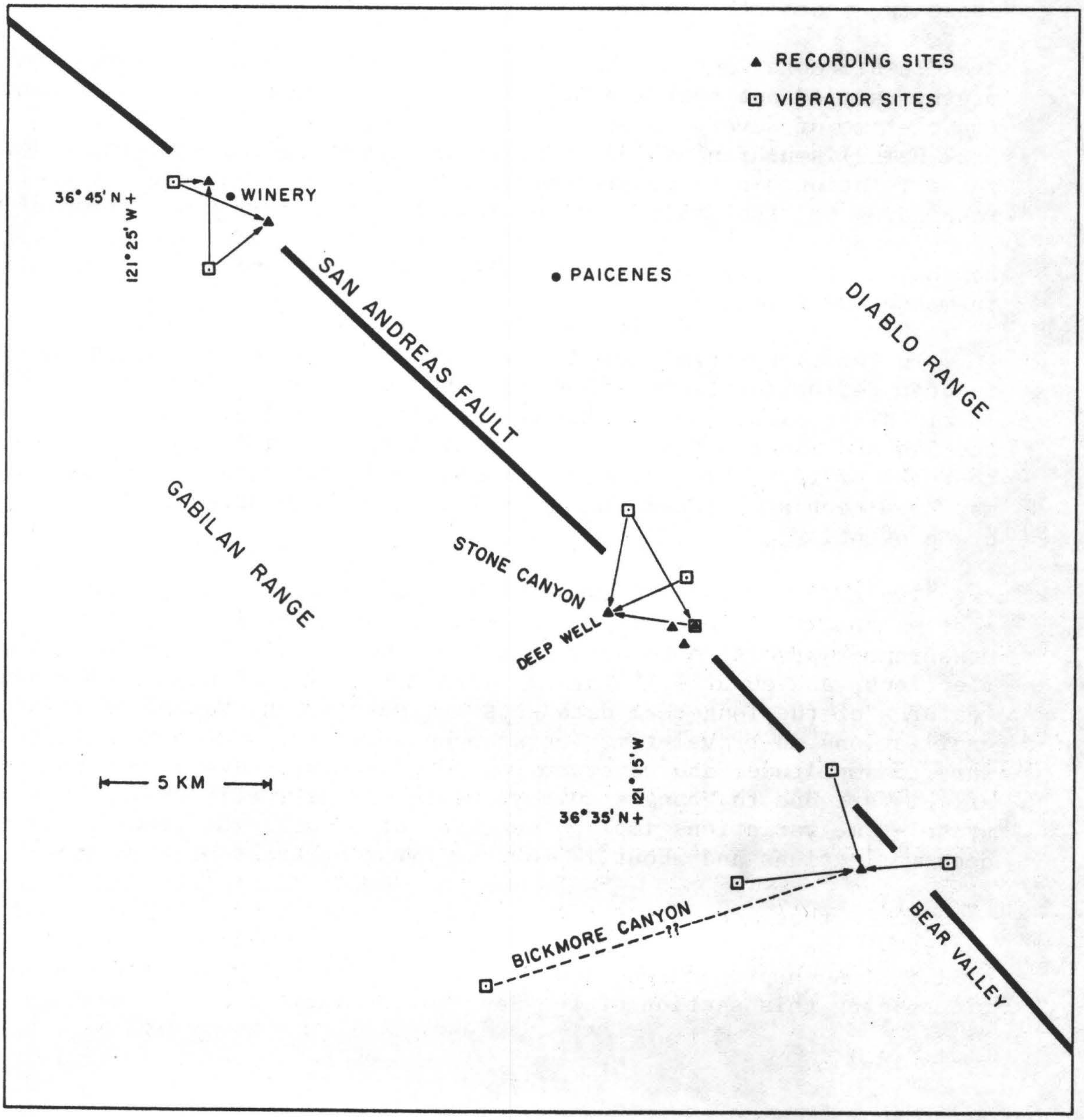

Figure 1. Proposed sites for future monitoring experiments.

Contract #14-08-0001-17759

Semi-Annual Technical Report

"Characteristics of Foreshocks and Short Term Deformation in the Source Area of Major Earthquakes"

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This proposal is to cover research on the characteristics of foreshocks and on special studies of individual earthquakes in order to understand the detailed time and space history of slip on faults.

With regard to foreshocks, we have made two studies. Lucile Jones worked in Peking (and has not yet returned) on a study of foreshocks of the Haicheng earthquake. An abstract of a paper to be given at the GSA meeting in the fall is enclosed as an appendix. We have also been making a systematic relocation of seismicity preceeding earthquakes in various regions, beginning with the New Hebrides. We have the relocations, but we have not yet begun the analysis of the data.

With regard to specific earthquakes, we have completed two studies. One deals with a peculiar sequence in the northern Pamir. An abstract of a paper in press with the JGR is given as an appendix. The second study considers a small event in southern Tibet, for which we could study both body and surface waves. Seismic moments from the body waves (T $\sim$ 10 sec) and surface waves (T $\sim$ 50 sec) agree well, implying no slow precursor or after slip.

Continuous Monitoring and Interpretation of Crustal Velocity Changes Near Palmdale, California

14-08-0001-16762

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Investigations

1. Seismic travel times from a stable repeatable pneumatic source located in Bouquet Reservoir 20 km west of Palmdale to boreholes 13 and 18 km from the source (see Fig. 1, Table 1) were examined for variations at the millisecond level over periods ranging from hours to months. Refraction lines, borehole soundings, and analysis of the airgun signal are used to identify the crustal origin of observed travel time variations.

Results

1. Seismic travel times can vary on the order of milliseconds of periods of several hours to days (Fig. 2, 4). Long term trends do not appear in the data. The data are not dense enough to correlate travel time variations with other stress/strain measurements, notably earthquake occurrence.

2. A geophone 300 meters from the source monitors the source stability; barring reservoir level changes, the source pulse is constant to 1 millisecond over 1/2 second of reverberations. Travel time variations observed at the receiver sites either originate within the crust over the intervening travel path or within seismic noise at the receiver. Figure 3 shows a sample pulse at the RR borehole. S/N is approximately 10/1 in amplitude. Figure 4 shows the time history of six zerocrossings in the RR signal (the remaining zerocrossings behave similarly). The first four zerocrossings, representing the first arriving energy, show coherent movement in time due to velocity shifts below 100 meters. The remaining zerocrossing, representing reflected energy interfering with later arriving direct energy, show related but different coherent behavior, due to velocity variations in the top 100 meters of the crust.

3. Two refraction lines on separate azimuths (N40E and N90E) through different lithologic and structural terrain show to first order similar velocity profiles (Table 2). These in turn are similar to velocities inferred from sounding the DS borehole and to calculations of velocities in a cracked rock medium using the expression of O'Connell and Budiansky.

Table 1.....Data on boreholes in this report

Name	Distance (km)	Depth (m)	Azimuth (N^0E)	Terrain
DS	17.9	750	40	Pelona schist overlain by quaternary alluvium
RR	12.75	100	80	Fault sump pond alluvium

Table 2.....Velocity Structures Inferred and Calculated

Depth (m)	Sierra Pelona Profile (a)	DS Profile (b)	DS Borehole (c)	Calculated (d)
100	1200	1200	1200	
200			2250	3500
400			3500	
750	4500	4500	4500	4500
1500	5500	5600-5700	(5500)[(e)]	5500

(a) 13 stations E of Bouquet, 5 km to 25 km
(b) 16 stations NE of Bouquet, 3 km to 25 km
(c) 11 positions up 750 meter borehole
(d) Cracked rock pinched shut by overburden; average crack aspect ratio, .0003; average orientation, 45^0 to vertical
(e) This value inferred from angle at which rays ascend borehole

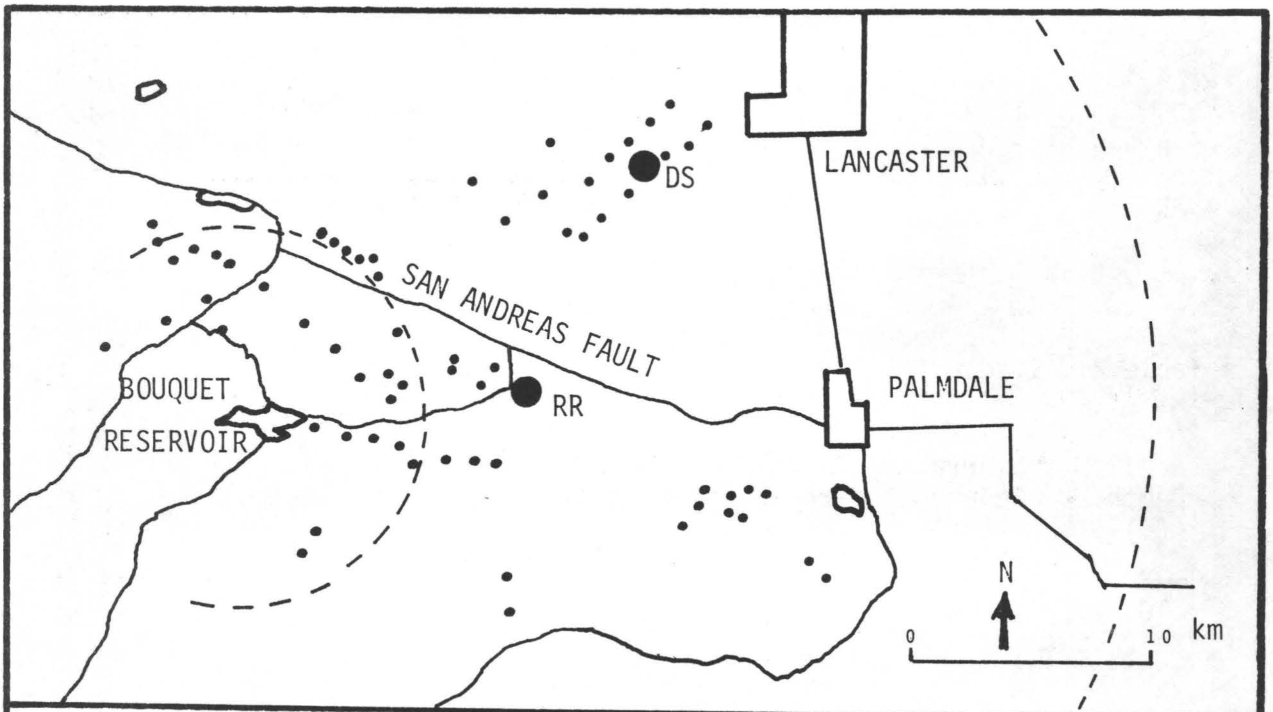

Figure 1. Bouquet Reservoir in relation to San Andreas Fault and Palmdale, California. Dots denote refraction profile sites. The NE profile includes the DS borehole and RR borehole. The eastern profile lies along the spine of the Sierra Pelona uplift.

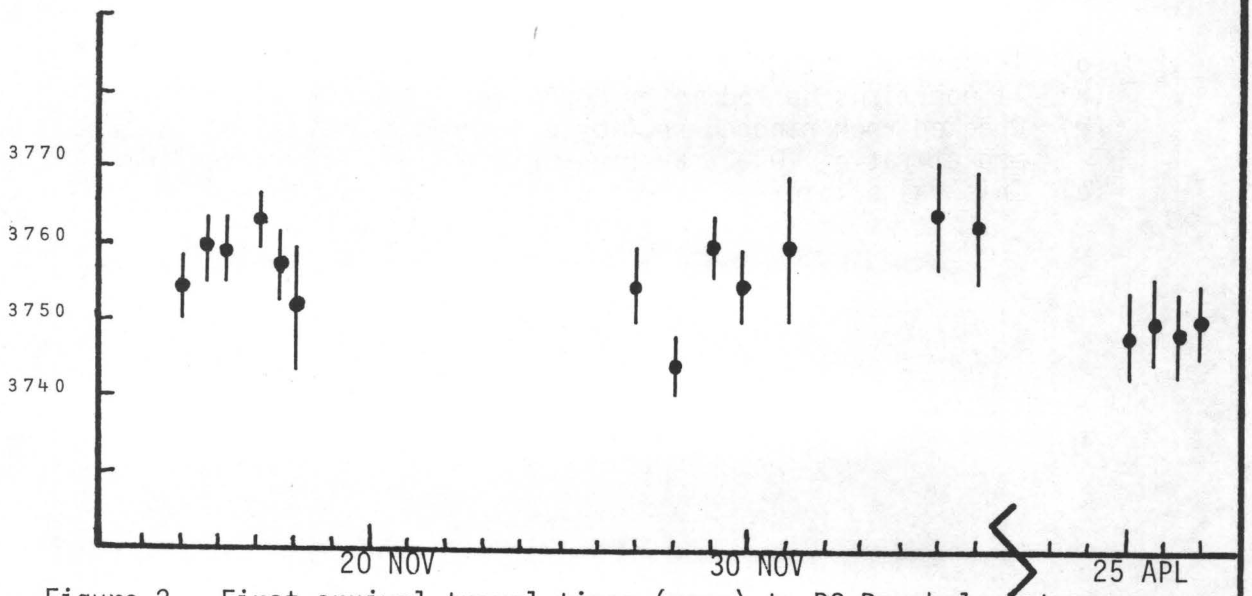

Figure 2. First arrival travel times (msec) to DS Borehole between November 14, 1978 and April 28, 1979. Digitization is in 4 msec intervals.

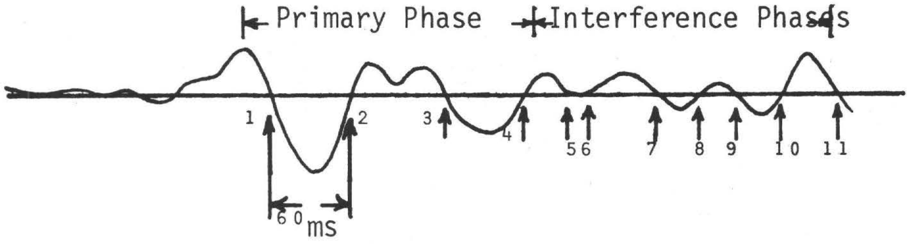

Figure 3. Airgun first and reflected arrivals at RR Borehole. Depth of sensor is 100 meters. Zero crossings 1, 2, 3, and 4 mark first arrival energy; subsequent zero crossings mark reflected first arrival energy interfering with later arriving energy (hence reduced amplitude and shorter zero crossing intervals).

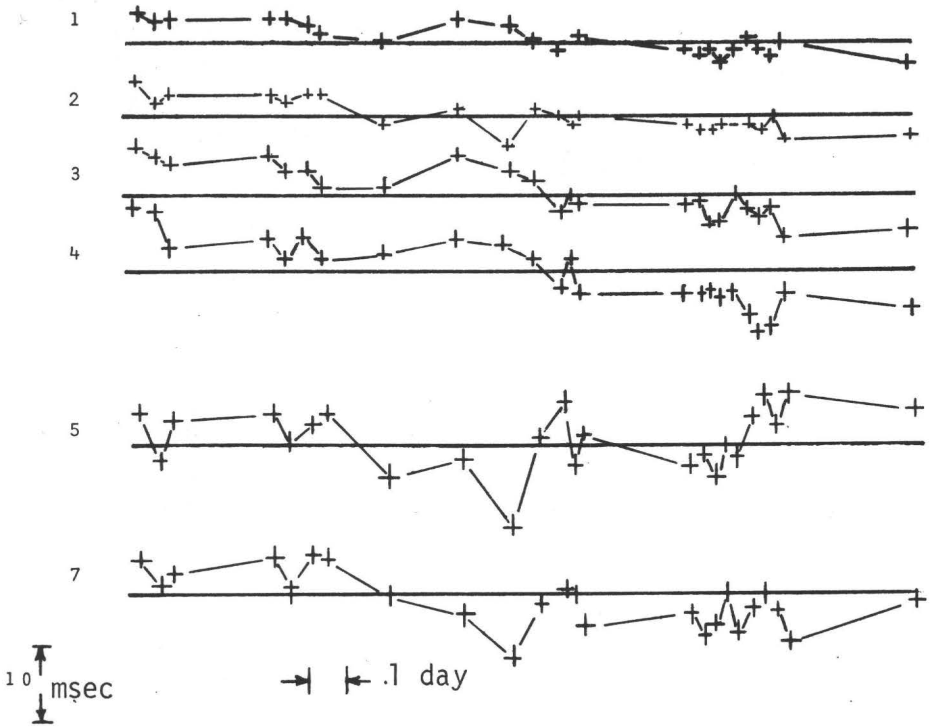

Figure 4. History of zero crossing times at RR Borehole during August, 1979. Digitization is in 1 msec intervals. Note the coherence of the energy groupings: zero crossings 1-4 belonging to first arriving energy (sampling the crust below 100 meters), and 5, 7, sampling the top 100 meters before and after reflection at the surface.

Precursory Seismicity Patterns Before Large Earthquakes

Contract No. 14-08-0001-17746

Summary by Dr. Max Wyss
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A systematic search was made for seismicity rate changes in the segment of the Kurile island arc from 42°N to 56°N by studying the cumulative seismicity of shallow (h $\leqq$ 100km) earthquakes within 11 overlapping volumes of radius 100 km for the time period 1960 through beginning of 1978. We found that in most parts of this island arc and most of the time the seismicity rate as obtained from the NOAA catalogue is fairly constant except for increased seismicity in the mid 1960ies in the southern portion due to the great 1963 mainshock there, and for seismicity quiescence during part of the time period studied within two well defined sections of the arc. The first of these is a volume of 100km radius around a 1973 (M_s = 7.3) mainshock within which the seismicity rate was demonstrated at the 99% confidence level to have been lower by 50% during 2100 days before this mainshock. The second volume of seismic quiescence coincides with the 400km long north Kuriles gap. In this gap the seismicity rate is shown (at the 99% confidence level) to be lower by 50% from 1967 to date, in comparison with the rate within the gap before 1967, as well as with the rate surrounding the gap. We propose that the anomalously low seismicity rate within the Kuriles gap is a precursor to a great earthquake, the occurrence time of which was estimated by the following preliminary relation between precursory quiescence time and source dimension $T = 214\ L^{0.54}$. We predict that a great earthquake (M > 8) with source length of 200 to 400km length will occur along the north Kurile island arc between latitude 45.5° and 49.2°N at a time between now and 1997 with a preferred date of 1982.

Creep and Strain Studies in Southern California

Contract No. 14-08-0001-16718

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This semi-annual summary report covers the six-month period from 1 April 1979 to 30 September 1979. The contract's purpose is to maintain and monitor strainmeters, creepmeters, tiltmeters, and alignment arrays across or in proximity to active faults in the Southern California region. Primary emphasis focuses on the San Andreas fault in the Cholame Valley and the Imperial and Brawley faults in the Imperial Valley.

CHOLAME VALLEY

The 3 fault crossing alignment arrays were each surveyed twice during the reporting period. The 4 continuously recording taut wire creepmeters, 5 recording taut wire strainmeters, and 3 recording biaxial bubble tiltmeters were maintained twice during the reporting period. At the northern end of the array the Work Ranch creepmeter continues to show steady dextral creep at an annual rate of 8 mm/yr for the six-month period. No other creep signals were observed and in particular, the Twisselman Ranch creepmeter, at the southern end of the array, continues to show no creep activity, thus delineating the boundary between the creeping and "locked" segments of the San Andreas fault. Coherent signals have not been observed on the strainmeters and the tiltmeters remain noisy showing principally diurnal, thermally induced signals. Persuant to the decision to telemeter signals from this array to the U.S.G.S. in Menlo Park, to permit real-time monitoring of activity for possible use in earthquake prediction efforts, all of the recent records for the recording instruments in the array have been transmitted to U.S.G.S. scientists in Menlo Park.

IMPERIAL VALLEY

Four of the 6 alignment arrays were each resurveyed once or twice during the reporting period and none showed significant motion. The 6 recording taut wire creepmeters and 3 recording biaxial bubble tiltmeters (the fourth is out of service and under repair), were each serviced twice during the reporting period. The creepmeter at Ross road showed two classic creep events during a 17 hour period on 23 May 1979. The two events combined to produce 13 mm total dextral offset. The tiltmeters, deployed in a 1 mile linear array, continue to show incoherent signals of predominantly diurnal period presumably of thermal origin. These instruments have been disappointing to date. The 2 nail files across the Imperial fault were each visited twice and show no movement.

OTHER INVESTIGATIONS

During the reporting period the following alignment arrays across the San Andreas fault were each resurveyed once or twice: BIG PINES, UNA LAKE, PALLETT CREEK, CAJON, INDIO HILLS, DILLON ROAD, DEVERS HILL, NORTH SHORE, and SANTA ANA WASH. These arrays are all located along the "locked" stretch of the San Andreas fault and none showed significant motion since previous surveys, which are done at maximum intervals of one year.

Manuscript in review:

Goulty, N.R., P.M. Davis, R. Gilman, and N. Motta, Meterological noise in wire strainmeter data from Parkfield, California: Seismol. Soc. Amer. Bull.

Vertical Deformation Studies in two Island-Arc Seismic Gaps in the U.S.
14-08-001-17679

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Palisades, New York 10964

SUMMARY

Investigations

Vertical deformation is being measured in seismic gaps in the hope of observing preseismic deformation in the epicentral region of a large earthquake:

(1) An array of mean sea-level instruments is being operated in the Shumagin Islands

(2) Following the February 28, 1979 Mt. St. Elias earthquake, the adjacent Yakataga seismic gap was instrumented with strainmeters and geodetic level lines.

(3) Uplifted marine terraces in the Yakataga region are believed to be due to historical earthquakes and attempts are being made to date them.

Results

A logging operation near Icy Bay, Gulf of Alaska towards the eastern edge of the Yakataga seismic gap allowed us to observed uplifted marine terraces and to date them tentatively by counting tree-rings on the oldest trees on each terrace. Each terrace has a fairly well defined maximum tree age, implying that that terrace was uplifted from sea level shortly before that date. This allows us to deduce earthquakes in 1280, 1390, 1560 and 1899 having associated uplifts of 24 m, 10 m, 18 m and 6 m. The large uplifts may be the result of more than one smaller earthquake of which only the latter remains recorded as a terrace. However, the implied uplift rate prior to 1560 (10 cm/yr) is surprisingly high and we suspect that the older dates may be in error - perhaps because 700 years is near the maximum age of Sitka spruce and Western Hemlock, the tree types in question.

Three sets of three constant tension carbon-fiber strainmeters were installed in the Yakataga region during July and August, at Katalla, Cape Yakataga and Icy Bay. It is too early yet to interpret data from them. A 2 km north-south level line was measured at Cape Yakataga.

The mean sea-level array in the Shumagin Islands presently consists of only two instruments.

Data from the strainmeters and sea-level gauges are being transmitted via the LANDSAT satellite to Lamont with a delay of less than two weeks. This allows the possibility of detecting a precursive signal.

Reports

"Satellite telemetry of sea-level data to monitor crustal motions in the Shumagin Islands region of the Aleutian arc", John Beavan and Roger Bilham, In: Terrestrial and Space Techniques in Earthquake Prediction Research, ed. A. Vogel, Friedr. Vieweg and Sohn, Wiesbaden, pp. 269-283.

TECHNICAL REPORT SUMMARY Contract #14-08-0001-17735

MONITORING STRESS LEVELS ALONG ACTIVE FAULTS, SOUTHERN CALIFORNIA

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During the period April 15 — October 15, 1979, major improvements were made to the Stress Monitoring Net along the San Andreas and Sierra Madre fault systems in southern California. The improvements included replacement of failed or weak sensors at several locations, addition of redundant sets of sensors at most sites, and the use of larger diameter boreholes to double the sensitivity of the instruments. Only two sites, San Antonio Dam along the Sierra Madre fault system at Upland, and Valyermo along the San Andreas fault southeast of Palmdale, have the original group of sensors and can be compared directly with the results obtained in the previous two years of monitoring. Both sites were monitored by telemetry during most of the period, and hundreds of measurements were made at each. Both sites show a continuation of earlier trends of stress change. The San Antonio Dam sensors have continued to indicate a substantial increase in stress in the north-south direction with a much smaller increase in stress in the east-west direction. The Valyermo site indicates a small reduction in compressive stress levels in the east-west direction and almost no change in the north-south direction.

The IRAD vibrating wire sensors were extensively calibrated in the laboratory during this period. They were found to have a sensitivity that is logarithmically related to the level of prestress under which they were installed. While there is some scatter in the data from gauge to gauge, the sensitivity can be estimated to be better than $\pm 25\%$ if the level of prestress is known. The sensitivity of the original gauges can thus be estimated reasonably well. All new gauges were calibrated individually. The improved calibration has led to some minor revision of the magnitudes of stress changes previously reported, but in general, the sites still show a characteristic north-south increase in compression.

Preliminary measurements using a new technique of grouting the sensors into a large diameter hole indicate that a sensitivity improvement of approximately a factor of six can be achieved by installing the sensor in an "elliptical" shaped hole. This is achieved in a standard 6- to 8-inch borehole by grouting in place a flattened tube containing the gauges. The cross-section of the tube is approximately elliptical and grout is prevented from entering the inside of the tube. The gauge is mounted across the narrow semiaxis of the tube and senses the stress concentration produced by the elliptical opening remaining after the grout has filled in the space between the tubing and the borehole wall. One installation of this system in the field is planned for FY 1980 at an existing site to compare with a standard installation. However, many of the installation details remain to be solved.

No earthquakes larger than magnitude 4 occurred within a reasonable distance (20 km) of any of the sites during the past year. Consequently, the ability of the sensors to detect preseismic or coseismic stress changes at near-surface (20 m) depths, or even the presence of such signals remains to be demonstrated. Based on the new calibration of the gauges and the numerous other preseismic and coseismic signals attributed to tiltmeters, magnitometers, etc., we believe that the sensors should be installed for maximum sensitivity. Thus the use of larger diameter (AX, 48 mm) boreholes instead of standard boreholes (EX, 38 mm) to double the sensitivity will improve the quality of the Net considerably.

Semi-Annual Technical Report for the period
December 9, 1978 - June 8, 1979.
U.S.G.S. Contract No. 14-08-0001-16759
Principal Investigators: Prof. Charles C. Counselman III
Prof. Irwin I. Shapiro
Massachusetts Institute of Technology, Cambridge, Mass. 02139
July 9, 1979

SUMMARY

Construction of the transportable very-long-baseline interferometry electronics system funded in Phase I of this contract, is not yet complete. Current status is as follows: (1) All component parts of the dual-band receiver have been delivered and tested; however, two of these components are undergoing repair by the respective manufacturers; (2) minor changes made to the design of the recorder controller are now being implemented; (3) all ASCII communicators have been received and are being tested.

The entire system should be completed and ready for site installation by October 1979. The transportable system will be placed first at the 100-meter-diameter- telescope near Bonn, Germany, and will be used simultaneously with compatible equipment at four other sites for the purpose of establishing baseline vectors between the various sites with reliable estimates of the repeatability.

MEASUREMENT AND ANALYSIS OF THE NEAR-SURFACE STRESS FIELD* IN THE VICINITY OF ACTIVE FAULTS IN SOUTHERN CALIFORNIA

14-08-0001-17703

Terry Engelder
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Goals:

The objectives of this project are to determine the state of stress along a portion of the San Andreas fault and to model the observed stresses using finite element analysis in terms of strain history and boundary properties and geometry.

The initial work on this project was done during 1977. This was reported by Sbar, Engelder and Tullis (1978) and Sbar et al. (1979). They showed that the stress field near the San Andreas fault varied spatially, based on two types of strain-relief stress measurements to depths of 3 m. Later, Zoback (1978 and personal communication) made hydrofracture stress measurements at four sites in the same area as the above measurements to a maximum depth of about 250 m. His results showed a change in orientation of the maximum compressive stress with depth in two holes near the fault. Both the near surface and the deeper measurements suggest that there may be a three-dimensional variation in the stress field near this portion of the San Andreas fault.

Presently, the measurements are too few and too widely spaced to be confident of any tectonic interpretation. The purpose of this phase of the project then is to make more measurements at some of the same sites as previously occupied and in between those sites. We will use both the U. S. Bureau of Mines and Doorstopper strain-relief techniques and sample to depths of 15 m to 20 m instead of 3 m as before. We will also experiment with shear wave velocity anisotropy as an indicator of the present stress field in these same vertical holes.

Investigations and Results:

To model both the magnitude and spatial variation in observed stresses near the fault, a finite element analysis is being undertaken. Preliminary analysis has been restricted to two-dimensional horizontal models, with emphasis being placed on concentrating strain in the models to be near the fault and on determining the effects of various boundary conditions applied on the edge of the models. Anisotropic elements are being included to model elastic parameters whose values may depend on orientation with respect to the fault. These elements, when applied to models that include both fault geometry and strain history, will be used to study the horizontal spatial variation in observed stress. Two-dimensional vertical models will

*This research is being done jointly with M. L. Sbar and R. R. Richardson of the University of Arizona.

also be considered to study the variation of stress with depth along the fault. These models must include a contribution to the stiffness matrix to account for the strength of the material normal to the vertical section being modeled. Again, the model stresses should depend on elastic properties, model geometries and strain history.

To date the equipment for this project has been purchased and preliminary two-dimensional finite element models have been run. We plan to start the field work at the end of May and continue with the modeling upon returning from the field in mid-July.

References:

Sbar, M. L., T. Engelder, and T. Tullis, 1978, Near surface in situ stress measurements along the 1857 break of the San Andreas fault in U.S.G.S. Open File Report 79-370, 485-501.

Sbar, M. L., T. Engelder, R. Plumb, and S. Marshak, 1979, Stress pattern near the San Andreas fault, Palmdale, California, from near surface in situ measurements, J. Geophys. Res., v. 84, 156-164.

Zoback, M. D., 1978, Measurement of in situ stress, natural fracture distribution and fracture permeability in a well near Palmdale, California, U.S.G.S. Open File Report 79-370, 597-613.

IMPROVED STRESS DETERMINATION PROCEDURES BY HYDRAULIC FRACTURING

USGS Contract No. 14.08.0001.17775

Charles Fairhurst and John Santich
Department of Civil and Mineral Engineering
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Minneapolis, Minnesota 55455
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Hydraulic fracturing of rock, first developed as a tool for stimulating oil well production, can also be used to measure in situ stresses in the earth's crust. The technique has the advantage over other stress measuring methods in that it can be used at considerably greater depths from a point of access. This is of great significance in earthquake regions where stresses at hundreds or thousands of meters are of interest. Despite the increasing use of hydraulic fracturing, however, there are uncertainties associated with the interpretation of the resulting data. In particular, confidence in the calculated maximum principal stress is less than in the minimum principal stress, although the former is often of greater moment. Furthermore, where the borehole axis is not parallel to a principal stress direction, the interpretation of hydraulic fracturing data with respect to stress magnitudes and directions is unclear. A series of experiments have been undertaken to clarify the effect of borehole orientation with respect to the in situ stress field, as well as the influence of pressurization rate on the resulting hydraulic fracturing data. Cubic granite specimens with 15 inch sides have been prepared for testing in a bi-axial loading frame. For the present series of tests no vertical stress will be applied so that the minor principal stress will always be zero. For the purpose of simplifying the effect of borehole orientation on the fracture process, the experiments have been divided into two series, with the inclined borehole axis remaining in either the σ_1 - σ_3 or the σ_2 - σ_3 plane. Borehole orientations ranging from 0^o to 36^o will be employed with two sets of principal stress values being σ_1 = 2000 psi, σ_2 = 1000 psi and σ_1 = 1200 psi, σ_2 = 1000 psi. In addition, selected tests will be carried out at three different flow rates, ranging from onefold to thirtytwofold the base flowrate.

Analytical studies have been carried out to investigate the influence of coupling between the pressurizing fluid flow rate and the resulting stress field. These studies follow on from earlier work reported in reference (1) and assume the rock to be a linearly elastic, isotropic homogeneous material. The material is also assumed to be impermeable, an assumption that would need to be modified in many field situations. Fluid pressurized joints are either completely closed (no fluid pressure), partly closed and obeying a Mohr-Coulomb criteria for slipping, or open (no shear resistance). Numerical solution of the model was through iterative approximation coupling a finite difference flow analysis and a displacement discontinuity (boundary element) stress analysis. A four block well model has been evaluated to assess the accuracy of the model and its numerical solution. P.B.3.

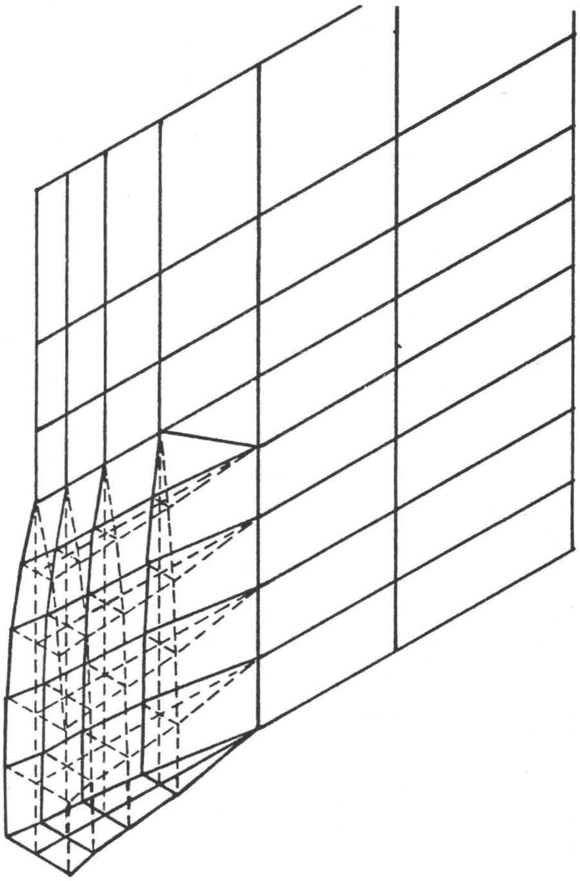
Coupled finite element analyses have been conducted on the experimental configurations using a two-dimensional axi-symmetric transient flow model coupled with a three-dimensional stress analysis developed in references (2 and 3). The solution involves an iterative loop to converge on the final solution with the crack area and aperture being adjusted to yield a stable flow rate. Figure 1a shows a slice through the three-dimensional finite element mesh used for the stress analysis with crack opening displacements superimposed, which Figure 1b is the resulting pressurization flow rate curve.

REFERENCES

1. Gronseth, J.M. and Detourney, E., "Improved Stress Determination Procedures by Hydraulic Fracturing", Final Report on USGS Grant 14.08.0001.16768, 1979.

2. Yukitoshi, Oka, et al.: Introduction of the Matrix Finite Element Method (Part 2), Suiyokaishi, 1970.

3. Hayato, Togawa, Japan Steel Structure Association: Computer Analysis of Matrix Structure, 1970.



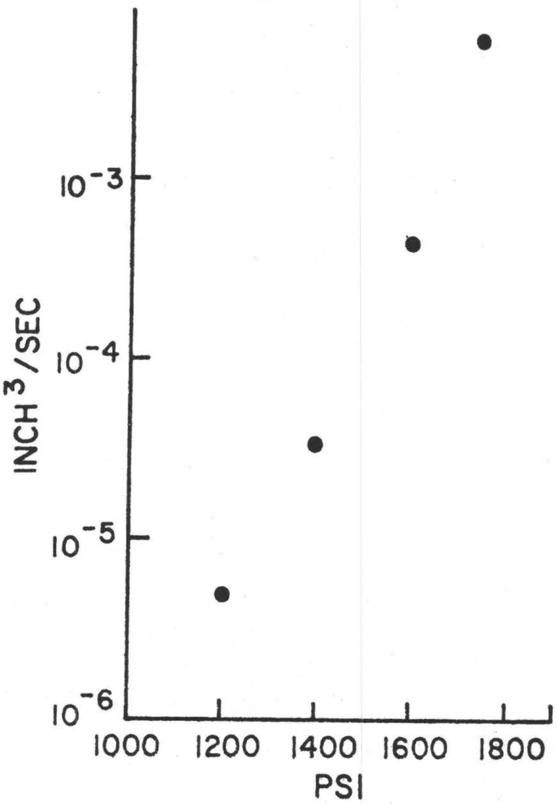


Figure 1: Finite Element Results

AN ASSESSMENT OF REFRACTION ERROR AND DEVELOPMENT OF METHODS TO REMOVE ITS INFLUENCE FROM GEODETIC LEVELING

14-08-001-17733

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Background

Releveling data has been very useful in helping to detect vertical crustal movements. However, systematic leveling errors can accumulate with distance and consequently degrade the leveling to the extent that it may lose much of its value as an indicator of crustal deformation. Although some terrain or position dependent systematic errors are not worrisome because they cancel out when two levelings are compared, refraction error is a concern because it is time and season dependent. Two levelings made in different seasons, may have different amounts of refraction error and consequently yield an erroneous "apparent" vertical movement when they are compared. The objective of this study is to critically assess the influence of refraction error on levelings, and to develop methods of modeling it so that appropriate corrections can be made. Theoretically, refraction error is greatest in the western U.S., where reliable leveling results are most critical to earthquake prediction and seismic hazard evaluation.

Results

A. Solar Radiation

Leveling refraction depends on temperature stratification near the ground (Kukkamaki, 1939). The temperature gradients near the ground, i.e., the lowest three meters, have traditionally not been measured. Consequently, it is necessary to model the vertical temperature profile using information from weather stations. The National Weather Service (NWS) has recorded solar radiation receipts for a period averaging 30 years at 192 well-distributed stations in the U.S. Average daily totals of solar radiation, for each month, associated with the latitude and longitude of the appropriate weather station were used as input to a least squares adjustment of a time-varying surface which enables prediction of mean daily total solar radiation anywhere in the conterminous U.S. This has been successfully accomplished. Other equations are necessary to convert the predicted daily total to instantaneous solar radiation. This involves calculation of the declination, zenith distance, and azimuth of the sun, given time and date. The known slope of the terrain, in the direction of leveling, is then used to calculate the angle at which the sun's rays are hitting the ground. The final value generated is then solar radiation appropriate for the time, season, and the direction and slope of the level route.

B. The Vertical Temperature Profile

The construction of the vertical temperature profile, from computed solar radiation is complex because many factors are involved; e.g., clouds, breezes, moisture and reflectivity of the ground, and roadside foliage. In the leveling records there is crude information about clouds and wind. Other factors must be ignored or standard values assumed.

To construct the vertical temperature profile, solar radiation is converted to net radiation using an equation given by Rosenberg, 1974. Upward sensible heat flux is calculated by subtracting heat flux into the ground, and evaporation flux, from the net radiation. A formula provided by Fraser, 1977, is used to compute the temperature at two particular heights. The temperature gradient is then computed and substituted into Kukkamaki's refraction formula for leveling. This algorithm has been developed successfully.

C. Application of the Refraction Correction to Leveling Data

The modeled refraction correction has been initially tested in several ways. However, the tests thus far are not conclusive. First, the discrepancies between the forward and backward leveled height differences were monitored to see if they lessened as a result of application of the refraction correction. The reduction in the sum of these discrepancies was insignificant, even when selective subsets of forward and backward levelings, done at times having distinctly different hour angles of the sun, were used. This was disconcerting, but understandable when it is realized that the forward and backward levelings are both accomplished in the daytime when the sign of the correction is the same. In the discrepancies, we are not looking at the whole refraction error, but only the difference between two refraction errors. The latter may be about the same magnitude as other uncertainties entering the computations as a result of assumptions about soil conditions, or inadequate knowledge of winds or clouds. Indirect testing was also accomplished by preparing two crustal movement profiles from levelings corrected for refraction. They were compared to their uncorrected counterparts to see if a more reasonable portrayal of deformation could be obtained. The result was encouraging. The two profiles which were constructed with levelings corrected for refraction showed more continuity in the direction and rate of motion between levelings. This test cannot be conclusive because the true motion is not known.

More study of the factors influencing refraction was accomplished on Maui, Hawaii, where temperature measurements were made at 5 different heights while leveling up and down Mt. Haleakala. Those measurements will also aid in testing the model which uses solar radiation to generate temperature at a particular height. Analysis of the data is now underway.

Another outdoor experiment is underway to specifically look for refraction. The test consists of setting up an instrument which looks at nine level rods set at prescribed distances and heights. Height differences and temperature gradients are measured. As the day continues refraction error should bias the height differences in a very systematic way. This experiment is being done to assess the real influence of refraction rather than relying on a strictly theoretical estimate of the extent to which it should manifest itself. This last type of testing should be most conclusive in determining the need for a refraction correction and in helping to select the best model for the correction.

References

Angus-Leppan, P.V., 1970. Heat Balance and Refraction in the Lower Atmosphere, Proc. Conf. on Densification of Geodetic Networks, Budapest.

Angus-Leppan, P.V., 1971. Meteorological Physics Applied to the Calculation of Refraction Correction, Commonwealth Survey Officers Conference, Paper No. 85, 9.

Angus-Leppan, P.V. and Webb, E.K., 1971. Turbulent Heat Transfer and Atmospheric Refraction, General Assembly IUGG, Moscow, Section 1, 15.

Deacon, E.L., 1969. Physical Processes Near the Surface of the Earth, World Survey of Climatology, 2 (General Climatology), 39-104.

Fraser, C.S., 1977. The Empirical Determination of Sensible Heat Flux for Refraction Correction. Uniserv G 27 (1977), p. 42-51, Univ. NSW Sydney.

Geiger, R., 1975. The Climate Near the Ground, Harvard University Press.

Hytonen, E., 1967. Measuring of the Refraction in the Second Leveling in Finland, Publication of the Finnish Geodetic Institute, No. 63, Helsinki.

Kukkamaki, T.J., 1939. Formulas and Tables for Computation of Leveling Refraction, Publ. Geod. Inst. No. 27, Helsinki.

Rosenberg, N.J., 1974. Microclimate: The Biological Environment, John Wiley and Sons, New York.

Webb, E.K., 1969. The Temperature Structure of the Lower Atmosphere, Proc. of REF-EDM Conference, Univ. NSW, Sydney (1968), p. 1-9.

PROJECT TITLE: TWO-COLOR LASER GEODIMETER
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INDEPENDENCE OF METEOROLOGICAL PARAMETERS: The Terrameter makes a direct and precise measurement of the refractive index simultaneously with distance measurements at two optical wavelengths, one in the red and one in the blue portions of the spectrum. The instrument calculates correction terms from the optical pathlength difference between the two lasers and computes the corrected base line distance. This automatically eliminates the first order effects of temperature, air pressure, and water vapor.

IMPROVED MEASUREMENT PRECISION: The two-laser Terrameter automatically corrects for the atmosphere by obtaining an immediate and direct measurement of the index of refraction simultaneously with the distance measurement. This technique, which uses a red He-Ne gas laser (632.8 nm) and a blue He-Cd metal vapor laser (441.6 nm), is based on the fact that the refractive index of air is dispersive in the visible spectral region. Hence, two optical signals will travel at slight.y different velocities. Since the refractivity is proportional to the density of air, the difference in refractive index (and thus the difference in the transit times for the two signals) is also proportional to the average air density over the path. A measurement of this difference is used to determine the average air density over the path. Knowing the average density, the average group index of refraction can also be calculated.

To obtain the correct pathlength, the Terrameter accurately measures the optical pathlength for the red light, D_R, and the blue light, D_B. The correction is then computed using the following equation:

$$D = D_R - A_R (D_B - D_R)$$

Where A_R is approximately constant. As A_R is a weak function of pressure, temperature, and water vapor, the accuracy of the distance measurement is better than 1 part in 10^7 for even coarse estimates of temperature, pressure, and water vapor.

THEORY OF OPERATION: The basic concept of the Terrameter is that of the Fizeau velocity of light experiment. Light is passed through a cog wheel modulator to a distant retro-reflector and is returned through the modulator to the photodetector only if the transit time of the light is exactly equal to an integral number of modulation periods. Red and blue light from the He-Ne and He-Cd lasers enters a Wollaston prism at the proper angle and polarization to make the outgoing beams collinear. The light passes through a microwave modulator that modulates the ellipticity of the polarized light at 3 GHz. The light is then transmitted by a Cassegrainian telescope, tra-

THEORY OF OPERATION (CONT.)

verses the path being measured, and is returned by a retro-reflector. The beam is received by the same optics used for transmission and passes through the modulator a second time where the ellipticity of the polarization is increased or decreased depending upon the phase of the modulator excitation. The beams emerging from the prism are separated by color and directed to the photodetectors. The analog outputs of the photodetectors are processed and used to control the modulator frequency for each color. The frequencies are continually adjusted so that a minimum of light is received at the photodetectors.

FIELD OPERATION: The tripod with yoke assembly is leveled and centered over a reference mark using the combination of optical plummet and cross-slide system. The optical plummet is built into the yoke, which has full 360° rotation for field verification of plummet alignment. The plummet also has independent focusing for reticule and station point. The cross-slide system provides orthogonal translation for centering the yoke. After centering, only slight releveling of the yoke is necessary.

Next the optical head containing the lasers, modulator, and microprocessor-based readout is placed on the yoke where it is guided into place and automatically engaged to the pointing controls. The centering of the instrument over the reference point is verified; slight adjustments are made to reposition the assembly more precisely if necessary.

The optical head is connected to the power supply and power is turned on. The laser beams from the instrument are directed to a distant retro-reflector. A 24-power aligning telescope in the head is used to acquire the reflected beam. The operator can then fine adjust the pointing of the instrument by viewing the frosted glass aperture mounted on the rear of the head. The precision vertical and horizontal tangent screws are adjusted until the light is centered in the frosted glass.

The appropriate environmental values are entered with the instrument panel switches. These include approximate distance, temperature, relative humidity, and barometric pressure. The Terrameter is completely automatic at this point. The corrected distance will appear on the digital display.

PORTABILITY: The Terrameter is a compact instrument that is modularized to enhance portability. The yoke, instrument head, and power supply are separated for ease of set-up, packing, and carrying. The yoke assembly shown in the accompanying photograph weighs 18 pounds and consists of the alti-azimuth mount, optical plummet, and tribrach. The instrument head with all of the computing electronics weighs only 75 pounds.

SIMPLICITY OF OPERATION:

- The optical plummet is built into the yoke and rotates with it for quick, easy checking; independent focusing for reticule and station point are added features.
- The cross-slide translating head provides rapid centering with a minimum of releveling.

SIMPLICITY OF OPERATION (CONT.):

- The separate yoke and instrument head allow easy handling and fast set-up. The head automatically engages when placed upon the yoke.
- The alignment telescope is 24-power for ease of alignment.
- The precision tangent screws provide fast pointing and beam acquisition.
- The readout is a large digital display.

Tilt Measurements in the New Hebrides Island Arc: Search for Aseismic Deformation Related to Earthquake Generation in a Major Zone of Lithosphere Subduction

14-08-0001-16703

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Investigation and Results

A sequence of moderately large earthquakes occurred in the New Hebrides Island arc in August 1979 near Efate Island. Located on Efate is the southern end of the seismograph network in addition to three bubble level tiltmeters, a long - baseline (100 m) half - filled water tube tiltmeter and a one km leveling array. The first large shock (Ms = 6.2) occurred on August 17, 1979 at a shallow depth within or possibly adjacent to the zone of underthrusting along the convergent plate boundary. Located at a straight - line distance of about 50 km from the instrumentation network, this earthquake is the largest event recorded by all instruments at the present time.

The seismograph network recorded a foreshock sequence of small magnitude earthquakes starting a few days before the first large shock. Abundant aftershocks were recorded including 10 with magnitudes (mb) greater than 4.2 (and located by the PDE) in the first 2 days. The events were well - recorded by the seismograph network. Preliminary data analysis shows a pattern of aftershock activity that migrates away from the first large shock and toward the trench with time. The second large event (Ms = 6.1) occurred on August 26, 1979 about 100 km from the instrumentation network. This event was also followed by numerous aftershocks including three large enough to be located by the PDE. The overall sequence thus includes two event with magnitudes (Ms) of 6.1 - 6.2, seven events with body wave magnitudes between 4 3/4 and 5 1/2, another 5 events with body wave magnitudes greater than about 4 1/4, and hundreds of smaller events recorded and locatable by the seismograph network. Analysis of on - scale digital recordings indicates anomalously small amplitude short - period particle velocities for the first large shock compared to the second one.

The main shock was located within 50 to 60 km of three biaxial tiltmeters, a long baseline tiltmeter and the Devils Point levelling array. Beginning in 1979 the leveling arrays have been levelled every three months, and the August sequence of events occurred between two such levellings of the Devils Point array. Analysis of the levelling data is proceeding. A preliminary analysis of the biaxial tiltmeter records indicates no obvious precursory signals associated with the August 17th event. More detailed analysis of the tiltmeter records is proceeding to establish a clear result.

The long baseline tiltmeter, which consists of two 100 m. tubes each half - filled with water, is still in the developmental stage. Since the monitoring electronics were installed in May 1979 the records obtained have been about 60 % continuous. Both the electronics and the mechanics of the detection system have required a number of modifications, and determination of the long - term stability of the instrument was not made.

The seismograph network continues to operate well. Six additional permanent seismograph stations were installed during the summer field season. These stations extend the coverage of the network northward into the islands of Santo and Aoba. This extension nearly doubles the coverage of the seismic zone by the network. A new microprocessor-controlled delay system was installed at the base station on Efate. The microprocessor software is being further developed to eventually replace all hardwire delays, triggers, and comparators used in the triggered, event-recording system.

Monthly seismicity maps are being produced with a delay of about two or three months. The maps show that much of the earthquake activity in the central New Hebrides occurs in clusters which vary in space and time. Analysis of this variation and its relationship to the space-time pattern of large earthquakes is proceeding.

Reports

Isacks, B.L., Hade, G., Campillo, R., Bevis, M., Chinn, D., Dubois, J., Recy, J. and Saos, J.-C., 1978, Measurements of tilt in the New Hebrides Island arc: in Proceedings of Conference VII Stress and Strain Measurements Related to Earthquake Prediction, U.S. Geological Survey Open - File Report 79-370, p. 176-221.

Isacks, B.L., Coudert, E., Cardwell, R., Barazangi, M., Louat, R., Latham, G.V., Chen, A., and Dubois, J., 1979, Results from a land - OBS seismograph network temporarily deployed across the southern New Hebrides Island arc: Earthquake Notes, v. 49, p. 29.

Cardwell, R.K., Isacks, B.L., Louat, R., Latham, G.V., and Chen, A., 1979, First results from a new seismograph network in the central New Hebrides island arc : EOS, Trans. Am. Geophys. Union, v. 60, p. 338.

Bevis, M., Isacks, B.L., Hade, G., Campillo, R., and Recy, J., 1979, Monitoring tilt in the New Hebrides Island arc : EOS, Trans. Am. Geophys. Union, v. 60, p. 316.

Louat, R., Dubois, J. and Isacks, B.L., 1979, Anomalous propagation of seismic waves through the zone of shearing contact between converging plates of the New Hebrides arc : Nature, v. 281, p. 293-295.

Tilt, Strain and Magnetic Field Measurements

9960-01189

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Investigation

1. Magnetometer arrays for tectonomagnetic investigations were installed in regions about 3600 km^2 at the north and south ends of the Alpine Fault, New Zealand and around active volcanoes in the North Island.

2. Oriented samples were collected for deformation and rotation studies as a function of distance from the Alpine fault.

Results

1. After correction for relative displacement of New Zealand since the Jurassic, paleomagnetic data indicate that the north Fiordland region in New Zealand has apparently remained relatively undeformed and unrotated for the last 100 million years since its Jurassic geomagnetic pole is in approximate agreement with the corresponding and Artic and Australian geomagnetic poles. This is surprising since 480 km of right lateral displacement has occurred on the nearly Alpine fault and more than 10 Km of uplift has occurred on the Southern Alps to the north.

2. Detailed study of the magnetic field records prior to the August 6, Coyote earthquake indicate no observable magnetic change occurred in the period from minutes to days before the earthquake and no coseismic step occurred at the time of the earthquake.

Reports

Johnston, M. J. S. and Mumme, T. C., 1979, Apparent stability of the Darran Mountain Block near the Alpine Fault, New Zealand. Trans. Am. Geophys. Un. (in press).

Mueller, R. and Johnston M. J. S., 1979, Preseismic and co-seismic magnetic field measurements near the August 6, Coyote Earthquake. Trans. Am. Geophys. Un. (in press).

Shapiro, V. A. and Johnston, M. J. S., 1978, Symposium on Tectonomagnetics and small scale secular variations held at IAGA/IAMAP Joint assembly at Seattle on Tuesday, August 22, 1977, J. Geomag. Geoelec., 30, 479-480.

Johnston, M. J. S. (1978) Local Magnetic Field Variations and Stress changes near a Slip Discontinuity on the San Andreas Fault. J. Geomag. Geoelec., 30, 511-522.

Smith, B. E., Johnston, M. J. S., and Burford, R. O., 1978, Local variations in magnetic field, Long-term changes in creep rate and Local Earthquakes along the San Andreas Fault in Central California. J. Geomag. Geoelec. 30, 539-548.

McHugh, S. and Johnston, M. J. S., 1979, A review of observations and dislocation modelling of some creep related tilt purturbations from central California in Terrestrial and space Techniques in Earthquake Prediction Research, Andreas Vogel (Editor), pp 181-201, Friedr. Vieweg and Sohn Braunschweig/Wiesbaden, Germany.

McHugh, S., Johnston M. J. S. and Mortensen, C. E., 1979, The implication of creep-related tilt observations on the San Andreas Fault in central California in Terrestrial and space techniques in Earthquake prediction research, Andreas Vogel (Editor), pp 161-179, Friedr. Vieweg and Sohn Braunschweig/Wiesbaden, Germany.

Johnston, M. J. S., Williams, F. J., Mc Whirter and Williams, B. E., 1979, Tectonomagnetic Anomaly During the Southern California Downwarp, J. Geophys. Res. (in press).

Johnston, J. J. S., Smith, B. E. and Mueller, R. J., 1979, Local Magnetic Field Measurements and Fault Creep on the San Andreas Fault, California, Tectonophysics (in press).

MEKOMETER MEASUREMENTS IN THE IMPERIAL VALLEY

Contract No. 14-08-0001-17698

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The objectives of this project, which was started more than eight years ago, are specifically to make a detailed study of movements on, and strain adjustment round, the Imperial Fault in the vicinity of El Centro, California, and more generally to look for evidence for fault activity elsewhere in the neighborhood. This is being done by repeated re-measurement of a network of geodetic stations about 800 m apart, which now numbers a little less than 300 stations, the most important part of which is a block of about 140 stations spanning the Imperial Fault.

During the period reported on, from 1 November 1978 to 30 April 1979, we spent six weeks in the Imperial Valley, but because less than four months had elapsed since the last re-measurement, the time was spent in adding stations and measuring the new lines, rather than in re-measuring existing lines.

Thus no new results were obtained. However, considerable strength was added to the Imperial Fault sector of the network. Specifically, (1) nine stations were added to the sector, and 152 new lines in it were measured, involving the new stations and stations constructed but not used in 1978, and (2) three small networks, involving 17 new stations, were constructed around the USGS/Caltech creepmeters spanning the fault at Ross Road, Heber Road and Tuttle Ranch, and a total of 45 lines within them were measured. The purpose of these networks is to provide a long-term check on the validity of the creepmeter results, which we plan to make use of in processing and interpreting our own results.

GEODETIC STRAIN MONITORING

9960-02156

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Investigations

1. A portable two-color laser geodimeter (Terrameter) was ordered in 1978 for the purpose of high-resolution trilateration surveys in selected areas of the San Andreas fault system.

2. Line length changes measured across the Hollister MWDM (Multi-Wave length Distance Measuring) network were analyzed to determine the pattern of ground deformation proceeding and following the August 6, 1979 Coyote Lake earthquake, which was located about 25 km toward the NW along the Calaveras fault.

3. Episodic line-length changes measured across the Hollister MWDM network were analyzed and the data inverted to determine corresponding models of slip on the Calaveras fault.

4. In Situ measurements of stress in the crust were analyzed to estimate the average variation of shear stress with depth and the state of stress in the vicinity of the San Andreas fault.

Results

1. The measurement program has not yet begun due to delays in the delivery of the Terrameter. The MWDM network in the vicinity of Juniper Hills, California was completed and progress has been made in establishing a network in the Anza-Coyote Canyon seismic gap. The latter network will extend from Anza to Pinyon Flat.

2. The ground deformation within the MWDM network was analyzed in terms of slip on the Calaveras fault plus a homogeneous strain change and it appears that during the year preceding the Coyote Lake event the rate of fault slip was about 8.6 mm/yr, which is low compared to the more usual amount of 15 mm/yr. There was a correspondingly high level of strain accumulation during the same period with a substantial component of shear strain parallel to the Calaveras fault. Following the earthquake a considerable amount of aseismic ground deformation was recroded in the Hollister area both by the MWDM instrument and two creepmeters. During the first 17 days after the earthquake, the analysis of the line length changes indicates between 5 and 6 mm of fault displacement and a substantial reduction in accumulated strain; this amount of fault displacement is consistent with that recorded by the two creepmeters.

3. Four episodes of deformation, that are convincingly identifiable in the MWDM data for the year following September 1975, can be modeled as right-lateral slip on the Calaveras fault and can be correlated with data from creepmeters within the network. Lower bounds on the moment (μAD, where μ is the modulus of rigidity, A is the area of fault slip and D is the average displacement) for each episode of slip were calculated using a linear programming technique. The results indicate that seismic slip is the dominant mechanism of strain release as the combined moment of 1.2 x 10^{24} dyne-cm for the four episodes far exceeds the moments of earthquake during the same time period. Creepmeter data taken in conjunction with the lower bound of the moment indicate that the aseismic slip extends well below the seismogenic zone.

4. The equations of equilibrium and compatability can be used to provide functional constraints on the state of stress. If the stress is assumed to vary only with depth Z then all non-zero components of the stress tensor must have the form A + Bz. In general, all non-zero components vary linearly with depth but at different rates which implies that the level of deviatoric stress increases linearly with depth. In support of this result, in situ stress determinations in North America, Southern Africa and Australia indicate that, on the average, the maximum shear stress increases linearly with depth to at least 5.1 km in the case of measurements in "soft" rock, such as shale and sandstone, and to at least 3.7 km for "hard" rock such as granite and quartzite.

A horizontal profile of measurements at depths near 200 m, reported by Zoback and Roller, near Palmdale, California were analyzed assuming that the shear stress varies with depth and along x, perpendicular to the strike of the San Andreas fault. The solution suggests that the average shear stress in the upper 8 km of the fault zone is about 35 bars less than the ambient level, which cannot be evaluated from the constant-depth information.

Reports

Langbein, J. O., The inversion of geodetic data for aseismic slip on the Calaveras fault, (abs.), EOS, Trans. Am. Geophys. Union, 60, 317, 1979.

TILT OPERATIONS

9960-01801

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Investigations

1. The tilt operations project continued to search for tilt precursors to earthquakes in California and Alaska, specifically by operating and monitoring tiltmeter arrays in central and southern California, totaling 61 sites, and an array in Alaska consisting of three sites.

2. Quality control was provided on tilt data received by monitoring telemetered data and occasional comparison with level array data. Improved detection and response to invalid data was provided through a program developed by Herriot and Silverman (project 9960-01189) that plots a one day sample of data, at three different scales, for each tiltmeter component, on a daily basis.

3. In Alaska, five new tiltmeters were installed, bringing to six the total number of instruments operating in that network. These instruments are distributed among three sites, with two each at Cape Yakataga, Icy Bay and Yakatat. The old Middleton Island site was abandoned and the new site at Icy Bay established in order to provide more complete coverage of the recently identified Cape Yakataga seismic gap. These instruments telemeter data via the GOES satellite, which necessitated development of digital interfacing circuitry.

4. Problems associated with the maintenance of tiltmeters in southern California were assessed and a strategy for improvement was implemented.

5. The White Oaks Ranch tiltmeter site, consisting of two instrument boreholes $6\frac{1}{2}$ m deep was refurbished after having been damaged by flooding. This site offers the opportunity to compare the performance of two different types of tiltmeters at double the standard installation depth.

6. Considerable time was spent trying to keep the operational and logistics planning aspects of an experiment involving the installation of five volumetric strainmeters on track. After some frustrations, the sites have been selected and permitted and drilling arrangements have been made, but installation now may be delayed by the winter rainy season.

Results

1. The Cape Yakataga, Alaska, tiltmeter record has been examined for any signal that may have been associated with the M=7.7, Mt. Saint Elias

earthquake of February 28, 1979. The earthquake epicenter was 80 km northwest of the tiltmeter site. The record, which begins in March 1977, shows some fluctuations that may be due to rainfall. However, for two months preceding the earthquakes, the east-west record trace is very steady at the two μradian level. At the time of the earthquake, large coseismic tilting associated with the elastic waves drove the recorder offscale. Following the coseismic tilting the east-west component decays over a period of several hours to a new level, implying a net tilt offset on the order of 10 μradians down-to-the-southwest, though an accurate figure is not available because the north-south trace remained offscale. Five days after the earthquake the north-south component returned from its down-to-the-south offscale position, and the east-west trace gradually returned to its pre-earthquake level. This post-seismic tilting may be contaminated by, or wholly due to rainfall.

2. Data from the Hamilton school tiltmeter near Anza in southern California was analyzed to determine the source of unusual event-like signals that appeared suddenly in the record of the generally well-behaved instrument, and persisted with increasing frequency over several months. Though there was an increase in seismicity in the area during the time period in question, there did not seem to be any systematic pattern associated with seismicity.

Reports

Mortensen, C. E., and M. J. S. Johnston, 1979, Preliminary results from comparisons of redundant tiltmeters at three sites in central California, Tectonophysics, 52, 85-86.

Mortensen, C. E., G. D. Myren, E. Y. Iwatsubo, and T. L. Murray, 1979, A prototype base length extension for borehole tiltmeters: EOS (Am Geophys. Un. Trans.), 60, n. 18, 325.

Iwatsubo, E. Y., and C. E. Mortensen, 1979, Short-term tilt anomalies preceding three local earthquakes near San Jose, California: EOS (Am Geophys. Un. Trans.), 60, n. 18, 319.

RECENT VERTICAL MOVEMENTS OF THE CRUST IN THE WESTERN UNITED STATES: REDUCTION AND ANALYSIS OF LEVELING DATA AND ITS INTERPRETATION IN LIGHT OF RELATED SEISMOLOGICAL AND GEOLOGICAL INFORMATION

14-08-0001-17625

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Background

Vertical crustal movement information has been derived from releveling data collected by the National Geodetic Survey (NGS) in the western U.S. Our objective is to determine to what extent this data base can contribute to our understanding of geodynamic phenomena with emphasis on earthquake prediction and seismic hazard evaluation. After critically examining the crustal movement information from a geodetic perspective, the leveling results are interpreted in view of other relevant geophysical and geological data.

Recent Results

I. Geodynamic Releveling: Confirmation of Contemporary Tectonic Deformation in Two Areas of the Western U.S.

Analysis of historic releveling data suggested rapid vertical movements in two areas of the Rio Grande rift: near Socorro, New Mexico, (Reilinger and Oliver, 1976), and east of El Paso, Texas (Brown et al., 1978). The National Geodetic Survey (NGS) recently completed releveling measurements specifically designed to further investigate possible deformation in these areas. These new measurements essentially confirm the original interpretation of historic leveling data and better define the spatial and temporal character of movements in both areas.

The Socorro, New Mexico area is characterized by a roughly elliptical uplift affecting at least 7000 km^2 directly above a mid-crustal ($\sim$ 20 km) magma body. The leveling observations are consistent (although not uniquely) with uplift at a constant rate of 5 mm/yr during the time the movements were monitored (1910-1979). The spatial coincidence of the zone of uplift and the magma body, persistent microearthquake activity (including swarms), and modeling results strongly suggest that the observed movements result from expansion of the Socorro magma body.

The area east of El Paso, Texas includes the Diablo Plateau-Salt Basin region, believed to represent the easternmost branch of the Rio Grande rift. New releveling measurements indicate uplift of this area at a more or less constant rate reaching about 4 ± 1 mm/yr. The progressive nature of deformation indicated by the releveling measurements, their large magnitude relative to possible leveling error, and the spatial dimensions of the uplift feature, strongly suggest a tectonic origin. Intracrustal magmatic activity or some form of preseismic deformation appear to be the most reasonable explanations in view of presently available geologic and geophysical information.

Apart from the important implications of these observations for the tectonics of the specific areas surveyed (e.g., uplift in West Texas could be preseismic in origin), these results demonstrate the ability of releveling measurements conducted for geodetic purposes to detect relatively subtle earth movements (rates ∿ few mm/yr; movements ∿ few cm). In this sense, confirmation of deformation in these two areas adds indirectly to the credibility of similar observations based on identical measurements in other areas.

II. Deformation due to Earthquakes and Active Faults

Recently we began a systematic analysis of possible fault-related vertical movements as evidenced by leveling measurements in the U.S. The objective of this project is to precisely locate active fault systems and determine the nature of the deformation associated with them.

This work is, for the most part, still in the development stage and our results are correspondingly quite preliminary. Thus far we have undertaken a review of published evidence of fault movements and have begun to examine the releveling data base for possible fault-related deformation. This work will continue during the next contract period.

In addition to our general study of fault-related movements, we have recently completed a detailed analysis of deformation possibly due to an earthquake in Texas. Releveling data indicate anomalous subsidence which may represent coseismic deformation of the 1931 Valentine, Texas earthquake. If this association is correct, then the epicenter for this earthquake lies considerably closer to Valentine than originally reported. These observations represent the first documented case of contemporary earthquake deformation in Texas.

III. Active Tilting of the Oregon and Washington Coastal Ranges

Tilted and uplifted marine terraces of Oregon and Washington show progressive landward tilting of the coast ranges at about 7 degrees per m.y. for the last 0.25 m.y. Seven resurveyed leveling lines running inland from the coast indicate contemporary landward tilt rates of about 1 to 9×10^{-8} rad. yr^{-1} (0.6 to 5 degrees per m.y.) averaged over periods of from 10 to 40 years. The leveling lines traverse, and the terraces cut across, dipping Cenozoic strata: Pleistocene (dips to 3°), Mio-Pliocene (dips to 30°) and Eocene (dips to 60°). At least four places (Cape Blanco, Bandon, Cape Arago, and Siuslaw River) are characterized by geodetic or terrace dips that have the same direction as the underlying stratal dips. Assuming a constant tilt rate as deduced from the geodetic and terrace observations, the strata dips suggest that deformation began 7 m.y. ago, perhaps due to a change to less rapid subduction of the Juan de Fuca plate at that time. The terraces and geodetic leveling document present-day deformation of the coastal ranges, most likely related to active subduction of the Juan de Fuca plate. The steep stratal dips, lack of major active faults and historic earthquakes, and presence of very young, reverse bedding-plane faults suggest that much of the onshore deformation within the overlying North American plate is taken up by folding rather than thrust faulting.

IV. Gravity Reobservations near Anchorage, Alaska

The NGS recently completed gravity reobservations (originally observed in 1964, 1965, and 1975) along a line extending east from Anchorage. This survey was conducted in order to investigate possible gravity changes associated with post-seismic deformation following the 1964 Alaska earthquake (Brown et al., 1977). We are presently in the process of applying tidal and drift corrections to the observations (including the earlier observations which have not yet been reduced). There are some indications of non-linear drift and instrument tares in the earlier surveys which will undoubtedly degrade data quality. Whether these observations are sufficiently accurate to detect density or elevation changes will not be clear until the data reduction is completed and individual surveys can be directly compared.

V. Map of Apparent Elevation Change for the Southern and Southwestern U.S.

The results of precise leveling carried out by the NGS have been compiled to generate the first statistically sound map of elevation change in the southern and southwestern U.S. The purpose of this project is to establish a consistent basis for evaluating possible anomalous movements and to determine relationships, if any, between regional elevation changes and geodynamic processes.

An interconnecting grid of observed elevation changes involving most of Alabama, Mississippi, Texas, Oklahoma, and New Mexico has been assembled. Apparent movements with wavelengths of less than 50 km were not considered in order to filter out effects due to benchmark instability and near-surface processes such as those due to fluid withdrawal. At the present time we have completed all computations and data processing that are necessary to apply the adjustment algorithm. The algorithm to be used was developed by scientists at the NGS and represents the most advanced technique for this type of analysis. A preliminary map of apparent elevation change for this area will be completed in the near future. (Supported in part by Nuclear Regulatory Commission Contract No. NRC-04-76-367.)

References

Brown, L. D., R. E. Reilinger, S. R. Holdahl, and E. I. Balazs, 1977. Post-seismic crustal uplift near Anchorage, Alaska, Jour. Geophys. Res., v. 82, pp. 3369-3378.

Brown, L. D., R. E. Reilinger, and J. T. Hagstrum, 1978. Contemporary uplift of the Diablo Plateau, West Texas, from leveling measurements, Jour. Geophys. Res., v. 83, pp. 5465-5471.

Reilinger, R. E., and J. E. Oliver, 1976. Modern uplift associated with a proposed magma body in the vicinity of Socorro, New Mexico, Geology, v. 4, pp. 583-586.

Publications

Adams, J., 1979. Active tilting of the midcontinent: geodetic and geomorphic evidence, EøS, Tran. Am. Geophys. Union, v. 60, p. 310.

Publications - Continued

Brown, L. D., and R. E. Reilinger, 1979. Releveling data in North America: implications for vertical motions of plate interiors, Report to Working Group 5 of the IUGG, in press.

Chi, S. C., R. E. Reilinger, L. D. Brown, and J. E. Oliver, 1979. Leveling circuits and vertical crustal movements, Jour. Geophys. Res., in press.

Ni, J. F., R. E. Reilinger, and L. D. Brown, 1979. Vertical crustal movements in the vicinity of the 1931 Valentine, Texas, earthquake, Geology, submitted.

Reilinger, R. E., L. D. Brown, J. E. Oliver, and J. E. York, 1979. Recent vertical crustal movements from leveling observations in the vicinity of the Rio Grande Rift, in: Rio Grande Rift: Tectonics and Magmatism, edited by R. E. Reicker, AGU, Washington, D.C., pp. 223-236.

Reilinger, R. E., L. D. Brown, and D. Powers, 1979. Confirmation of Tectonic uplift in the Diablo Plateau region, West Texas, Geophys. Res. Lett., in preparation.

Reilinger, R. E., J. E. Oliver, L. D. Brown, A. R. Sanford, and E. I. Balazs, 1979. New measurements of crustal doming over the Socorro magma body, Geology, submitted.

Reilinger, R. E., and J. E. York, 1979. Relative crustal subsidence from leveling data in a seismically active part of the Rio Grande rift, New Mexico, Geology, 7, pp. 139-143.

CRUSTAL STRAIN

9960-01187

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Investigations

1. Analysis of strain accumulation in central and southern California was the principal subject of investigation, although some analysis of networks elsewhere in western United States was undertaken. A detailed search of Geodolite measurements was made to detect possible earthquake precursors with negative results.

Results

1. Although numerous Geodolite lines have been measured annually for periods up to eight years preceding the August 6, 1979, Coyote Lake earthquake (M_L=5.9; located about 30 km southeast of San Jose, California) no unambiguous anomaly was observed to precede the earthquake and the coseismic length changes were only marginally detected. Most of the lines had last been surveyed about three months before the earthquake and resurveyed again in the month following the earthquake. The closest Geodolite station was only 4 km from the epicenter.

2. The epicenter of the October 4, 1978 earthquake (M_L=5.8) located about 30 km northwest of Bishop, California is only about 5 km from a Geodolite station in the Excelsior network. That network was surveyed in the summers of 1972, 1973, 1976, and 1979. The changes in length between the 1976 and 1979 surveys of the six lines in the vicinity of the epicenter of the October 4 event are within the uncertainties in measurement (i.e., less than 12 mm in a line length of 30 km) and there is no obvious indication of coseismic movement. In view of the fact that the coseismic movement could not be detected, it is rather unlikely that more frequent surveys would have detected an earthquake precursor.

3. A resurvey of the Geodolite network between Bishop and Lone Pine, California which spans the rupture of the 1872 Owens Valley earthquake indicates an accumulation of right-lateral tensor shear strain at the rate of about 0.08 $\pm$ 0.03 μstrain/a during the interval 1974-79. Level surveys indicate that the fault block west of the rupture is being tilted down to the east at an average rate of about 0.15 $\pm$ 0.03 μrad/a. These rates are consistent with those inferred from earlier surveys.

4. A resurvey of a Geodolite network near the crossing of the Alaskan pipeline and the Denali fault in southeastern Alaska indicates that right-lateral

tensor shear strain accumulated across the Denali fault in the period 1975-79 at the rate of 0.28 $\pm$ 0.05 μstrain/a, about twice the rate observed on the San Andreas fault in California.

5. The 1979 resurvey of a large aperture (1 x 4 km) level array on Middleton Island, Alaska, indicates that the island is undergoing complex deformation which cannot be approximated by uniform tilt. Thus, no conclusions concerning tilting of the offshore portion of the Alaskan plate in southeast Alaska can be drawn from the Middleton Island level surveys of 1974, 1975, and 1979. This is consistent with our experience elsewhere with surveys of level arrays.

Reports

Savage, J. C., Prescott, W. H., Liswoski, M., and King, N., 1979, Deformation across the Salton trough, California, 1973-1977: Journal of Geophysical Research, v. 84, p. 3069-3079.

Lisowski, M., and Savage, J. C., 1979, Strain accumulation from 1964 to 1977 near the epicentral zone of the 1976-1977 earthquake swarm southeast of Palmdale, California: Bulletin of the Seismological Society of America, v. 69, p. 751-756.

Savage, J. C., Prescott, W. H., and Mortensen, C. E., 1978, Geodetic measurement of tilt (abstract): Earthquake Notes, v. 49, p. 43.

MWDM Strain Measurements in Central California

14-08-0001-15877

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Investigation

1. A geodetic array near Hollister, California has been measured almost daily for the last four years using a multiwavelength distance measuring (MWDM) instrument. The array consists of nine primary lines and several secondary lines covering approximately 100 km^2. The lines are three to nine km in length and radiate from the MWDM instrument site in Hollister. The Calaveras fault bisects the MWDM array. A primary goal of the MWDM measurements is to improve the understanding of the processes of aseismic fault slip and associated earthquakes and crustal deformation.

2. The most significant seismic event to occur during the MWDM effort took place on the morning of 6 August 1979. The Coyote Lake, California earthquake (mag. 5.7) was located on the Calaveras fault approximately 25 km NNW of the MWDM instrument site.

Results

1. The long-term changes in line lengths within the MWDM array generally occur in fairly well-defined episodes that have been ascribed to slip at depth on the nearby faults. These episodes typically last for several weeks and are interspersed with periods of relative quiescence. During this reporting period, one of these episodes occurred. It began in mid March 1979 and continued at a fairly constant rate until mid June 1979. Line length changes as large as 10 mm were measured during this episode (see Table 1). The data suggested that most of the array deformation was consistant with a large ($\geq$ 20 x 20 km) dislocation surface NNW of Hollister.

Figure 1 presents the recent data from the three fault-crossing lines that extend to the NW: Knob, Goat, and Hudner. Shown in Figure 1 is the strain episode followed by a relatively quiesent period, the rapid "coseismic" deformation shown by arrows, and the substantial postseismic deformation.

When the entire array is considered in more detail, it appears that the central MWDM instrument site may have been displaced a few millimeters to the NNE during the strain episode. This is somewhat difficult to model since the instrument site is generally assumed to be east of the Calaveras fault (which locally strikes at approximately N 20° W). Figure 2 provides

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a possible solution to this problem; north of Hollister the Calaveras fault exhibits a significant change in strike (~N 20° W near Hollister to ~N 27° W near Coyote lake). Since the MWDM instrument site is located within a few hundred meters of the Calaveras, the axis of a large dislocation surface on the fault north of Hollister might pass to the east of the instrument site, this would allow a more northerly displacement.

	Strain Episode 18 Mar-26 June	Quiescent Period 26 June-4 Aug	"Coseismic" 4 Aug-6 Aug	Postseismic 6 Aug-22 Aug
Knob	+4.5	+0.5	+3.0	+3.0
Goat	+6.2	+1.0	+4.5	+5.5
Hudner	+10.0	+1.0	+6.0*	+3.5
Gambetta	-1.0	0.0	+0.5	+3.5
Easy	-8.2	+2.5	+1.2	+2.2
Fairview	-6.0	+1.2*	-4.7*	+2.0
Foothill	+1.2	0.0*	0.0*	+4.3*
Pereira	-4.2	0.0	+3.0	-3.0
Poison	+5.0	0.0	+2.0*	+2.5
Picket	+1.5	0.0	+2.5	0.0

Approximate line length changes within the MWDM array from 18 Mar 1979 to 22 August 1979. All changes are measured in millimeters.

2. Line lengths showed little change between mid June and 5 August 1979. Only the line to station Easy showed a large change in length during this period. The interpretation of this 2.5 mm increase in length is uncertain at this time and must be viewed with caution since this line has demonstrated instability in the past.

3. An abrupt extension of all the fault crossing lines to the north occurred on the day of the earthquake (consistent with approximately 5 mm of right-lateral slip). The postseismic deformation suggested that an additional 6-8 mm of slip has occurred between 6 August and mid September 1979.

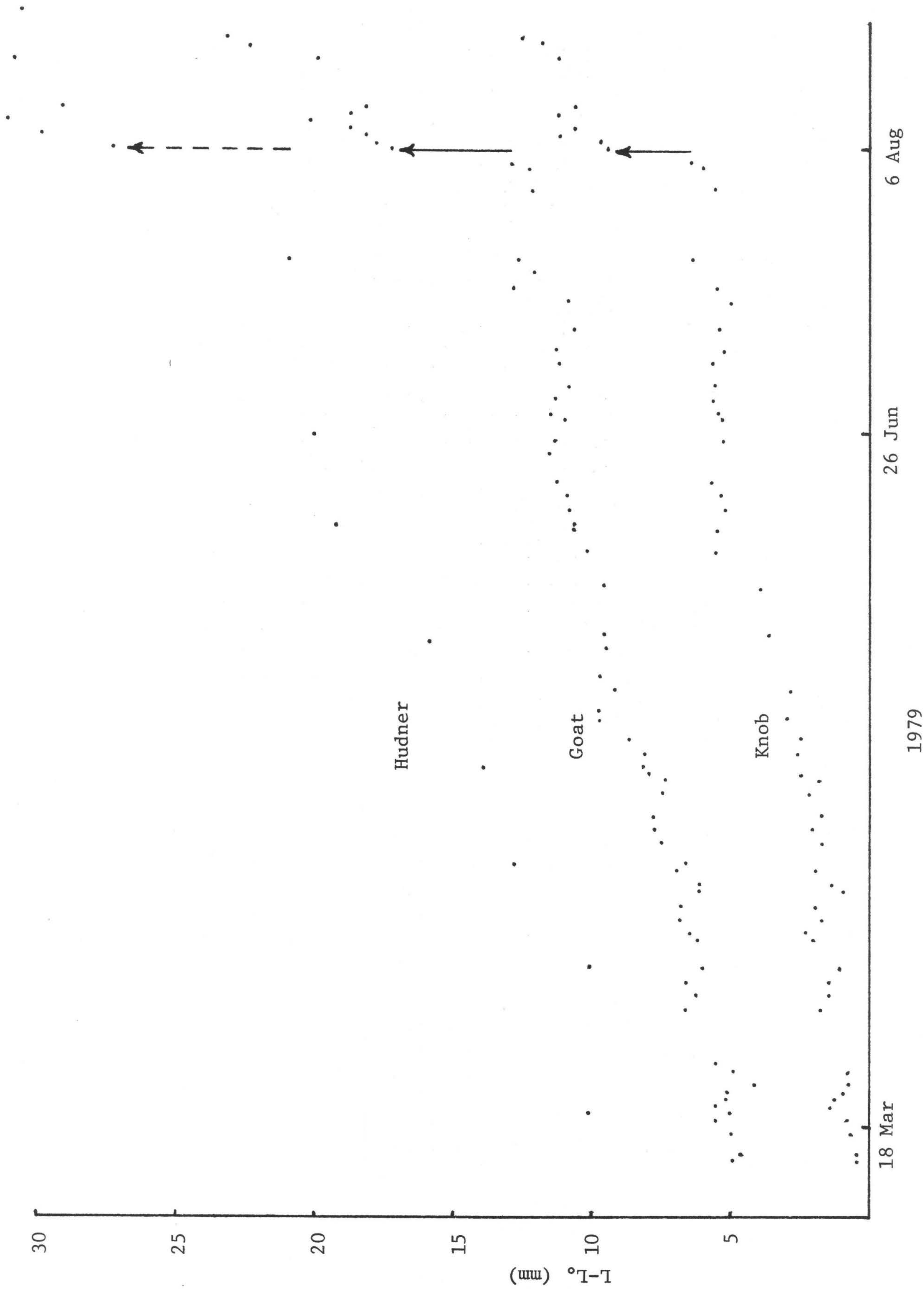
Reports

Slater, L. E., 1979. The strength of the Calaveras fault near Hollister, California: an indication from MWDM data. Transactions, American Geophysical Union, 60, No. 18: 315.

Slater, R. E. and L. E. Slater, 1979. A note on natural and man-made causes of benchmark instabilities. Transactions, American Geophysical Union, 60, No. 18: 234.

Slater, L. E., 1979. Can the ratios of single-wavelength EDM data improve the resolution of small changes in line length?: A comparison with multiwavelength EDM data. J. Geophys. Res., 84, 3659-3663.

*Infrequent data makes this estimate less certain.


Hudner
Goat
Knob
1979
18 Mar
26 Jun
6 Aug
30
25
20
15
10
5
L-L° (mm)

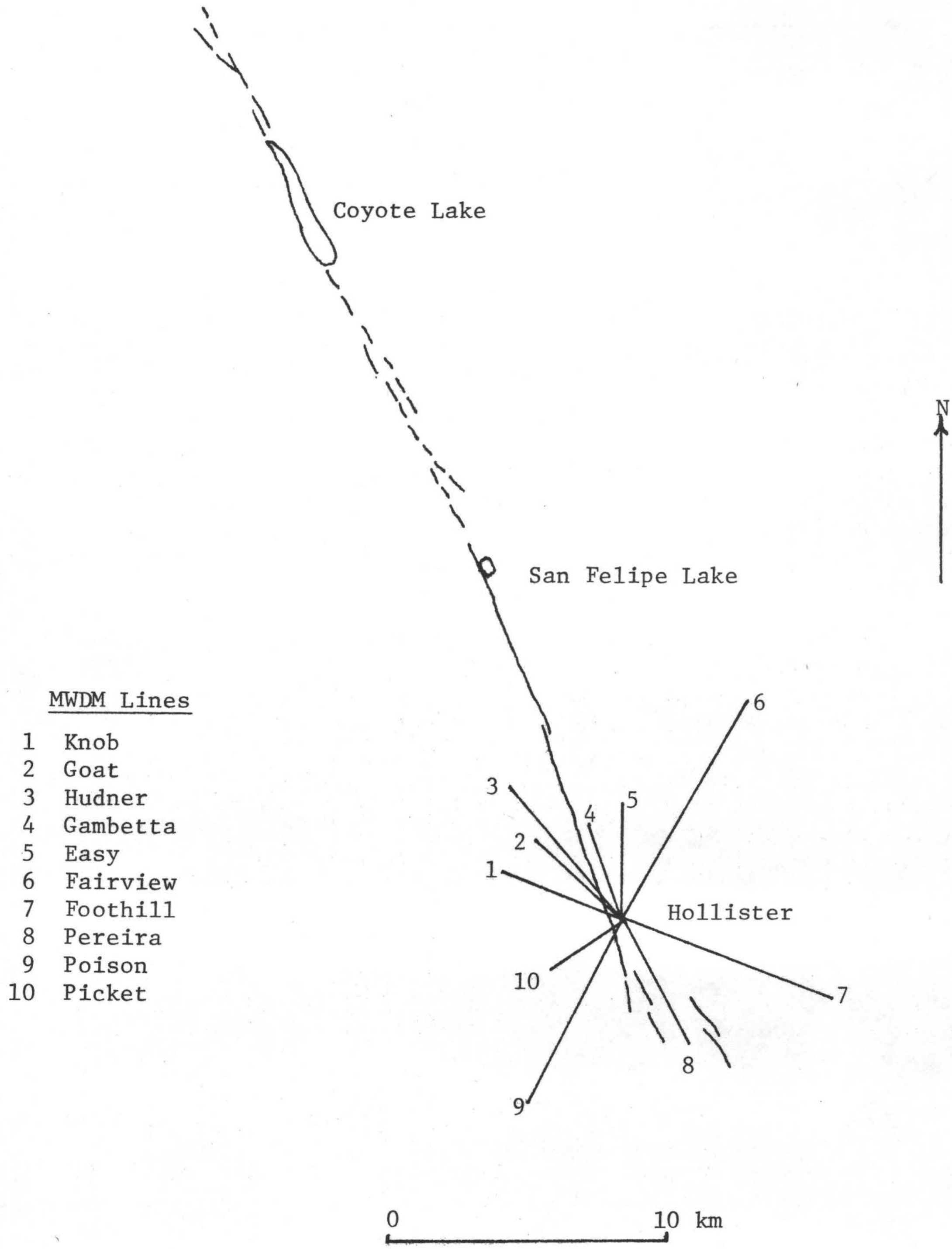


Figure 2. MWDM array in Hollister and Calaveras fault.

Tiltmeter Array in New Madrid

Semi-Annual Technical Report No. 5

Contract 14-08-0001-15848

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Summary

Investigations.

The overall objective of this project has been to explore the feasibility of monitoring crustal deformation in the New Madrid seismic zone in order to identify possible precursor patterns for use in earthquake prediction. The effort thus far has centered on the evaluation of a bubble-borehole tiltmeter as an instrument suitable to this purpose. The research has progressed by installing tiltmeters in pairs a few meters apart in order to investigate whether pairs of instruments can be shown to track one another, and to study what factors affect instrument performance. The work has proceeded through a number of tasks.

Task 1. Instrument qualification and preparation. Adjustments to TM-1 tiltmeters electronics and design of the auto-zeroing system have been satisfactorily completed in order to assure stable operation under extremes of climatic conditions at New Madrid and in Adak.

Task 2. Instrument installation. Techniques of interfacing the instrument to the physical environment in order to achieve long-term stability of the tiltmeter are still under development. Installation of the instruments in pairs is helpful to this end. Burial at greater depth, and installation with the tiltmeter itself packed to only half its length have proven useful.

Task 3. Effects of other physical processes in the instrument. The simultaneous monitoring of meteorological data, in order to correlate effects of changes in the near surface regime on the stability of the instrument, is just getting underway.

Task 4. Digital data acquisition system. A digital data acquisition system has been designed which will sample 16 analogue channels and 4 digital channels per station at 10 minute intervals and transmit data via FSK telemetry in a carrier band below the present 8 seismic audio

carrier channels over existing radio and telephone lines. Delivery has been received of the prototype remote digital transmitter and the first receiving/recording system. These units have performed satisfactorily in the laboratory, and are being field-tested at the present time. Incoming data are recorded on floppy disks for data processing.

Task 5. Data reduction. A scheme for data reduction, including removal of zeroing steps and a mode of presentation of the tilt and tilt-rate vectors are being developed.

Results.

Task 6. Data interpretation. Since a priority has been placed thus far on investigating the reliability of shallow bore-hole tiltmeter data, little has been done by way of relating recorded tilt data to possible earth tilts. Correlations have been noted, however, of coincidences of ground tilts and water level changes in wells following larger rainfalls. In several instances during the summer of 1978 large rainfalls occurred just prior to the occurrence of earthquakes in the New Madrid zone. The possible inter-relation of these observations is only beginning to be investigated.

In as much as this is a joint program with CIRES of Colorado University, the results of our efforts in producing coherent, stable tilt data can be seen in the latest data from the tiltmeter array at Adak, AK, in the Aleutians. Figure 1 is a sample of data from three of the Adak tiltmeters, spaced at about 1 km, from early September.

Reports.

Special technical reports were prepared as a result of the Adak field trips:

Morrissey, S.T., The Adak Summer Field Trip, 1978, A Special Technical Report, 18 pp.

Morrissey, S.T., The Adak Winter Field Trip, March 12-15, 1979, A Special Technical Report, 16 pp.

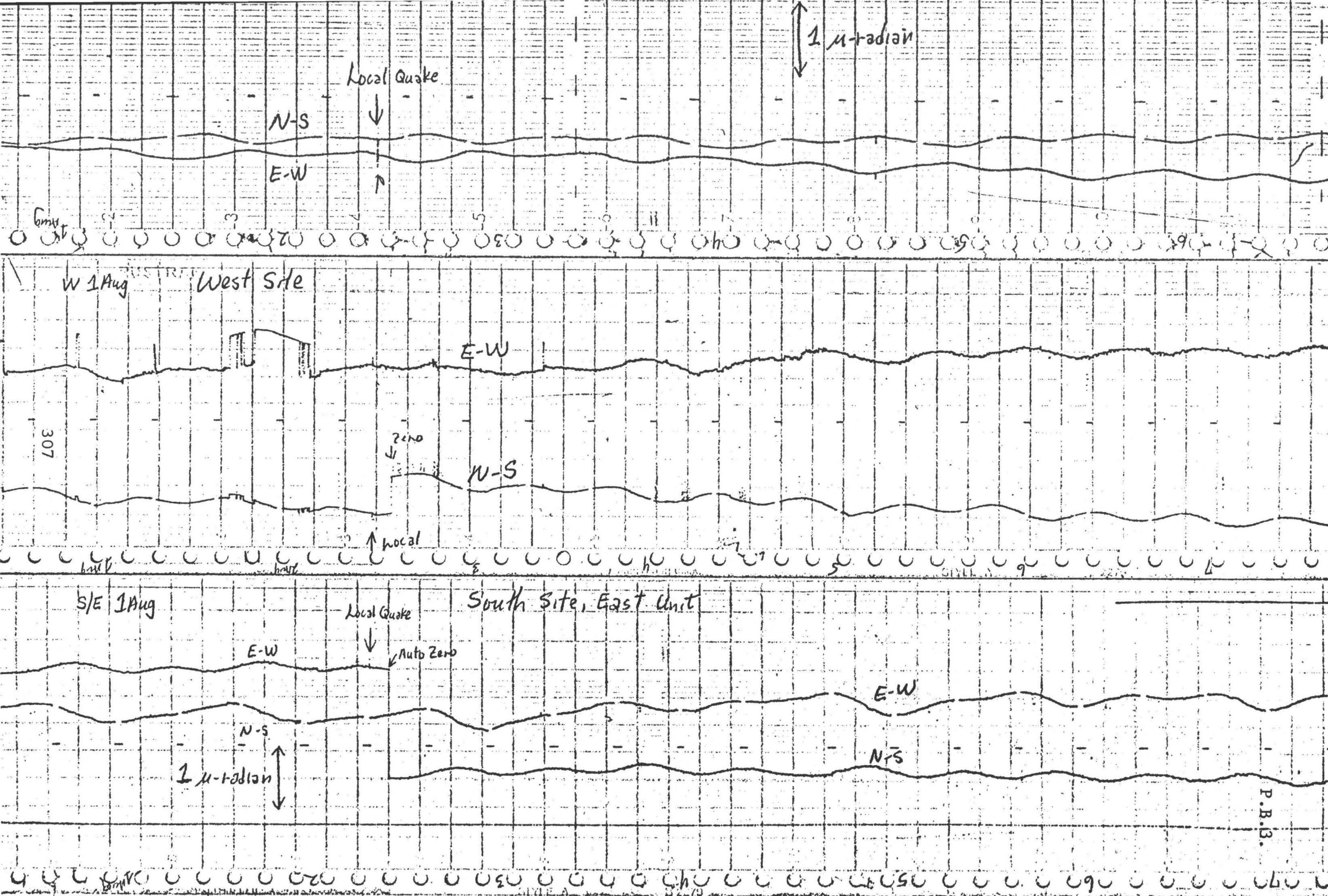

Figure 1. Adak tiltmeter data, 1 August and following.

Dry Tilt and Nearfield Geodetic Investigations of Crustal Movements, Southern California

14-08-0001-17685

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Investigations

By means of telescopic spirit leveling (dry tilt) of small aperture triangular arrays, precision leveling of short lines across faults, and precision surveying of alignment arrays and trilateration networks, we have been monitoring the following physical phenomena within the southern California uplift and in other areas of potentially active crustal movements:

1. The regional pattern and timing of tilt, if any, and
2. The nature of strain accumulation and release, if any, across well-defined active and potentially active faults.

During 1978-79 we resurveyed 45 dry tilt arrays from 2 to 12 times each. Most of the arrays are located along the San Andreas fault zone from Frazier Park to Cajon Pass. Others are located along the frontal fault system of the San Gabriel Mountains. Twenty-four of the arrays have been in place nearly 3 years, and others have been added more recently.

We have established 17 short level lines across active faults in such diverse places as San Fernando, Death Valley, Palmdale, San Juan Bautista and Santa Barbara. Some of these lines were established nearly 10 years ago and have accumulated as many as 13 resurveys. Others, such as one across the Pleito thrust at the south end of the San Joaquin Valley, were established in the present contract period.

Two alignment arrays established three years ago in the San Andreas fault were resurveyed once each in the past year.

Twelve trilateration arrays have been established across several faults in southern California in the last two years. Those in the San Andreas fault zone were surveyed once each in the past year.

Results

Eleven of 24 dry tile arrays extant in 1977-78 show anomalous tilts in winter and spring 1978 which we attribute to a slow release of strain along the San Andreas fault related to the Juniper Hills-Lake Hughes earthquake swarm (McNally and others, 1978). The tilts are variable in azimuth, magnitude, and distance (300m to 30km) from the San Andreas fault (Fig. 1), but they progress in time southeastward along the fault from Lake Hughes to Juniper Hills after the cessation of the main earthquake activity (Fig. 2). The earthquakes certainly represent the release of strain at two patches of the fault, whereas the tilt data suggest that the subsequent tilts are a manifestation of slow strain release in the gap between the two clusters of earthquakes. Anomalous tilts also occurred along the San Andreas fault just outside the gap, that is a short distance NW of Lake Hughes and SE of Juniper Hills. On the other hand, tilt on two arrays 30 km from the fault, whose tilt anomalies are identical in time and character to those near the fault, are difficult to relate to the tilt along the fault, because intermediate arrays were not similarly affected.

The Santa Barbara earthquake of August 13, 1978, was preceded by a tilt anomaly at a single dry tilt array about 15 km WNW of the earthquake epicenter. The anomaly started in October 1977, 10 months before the earthquake; by July 1978, the array tilted about 25 μrad to the north. The next resurvey of the array was done 4 days after the earthquake and showed another 20 μrad of tilt had occurred in the same direction. Before October 1977 and since the earthquake, the tilt varied only 5 μrad. Thus, the array seems to have recorded precursory tilt at least to July 1978. From July until 4 days after the earthquake, the 20 μrad of observed tilt may be a mixture of pre- , co- and post-seismic tilt.

Resurveys of the short level lines have documented only non-tectonic effects related to thermoclasticity and subsidence related to withdrawal of groundwater for agricultural irrigation. Where the irrigation is fairly continuous and involved large withdrawal volumes that exceed recharge rates (San Juan Bautista, Duravan Ranch), the subsidence is episodic in detail but continuous in annual rate and direction. Where the withdrawal is of small volume and less than presumed recharge rates (Pallett Creek) the subsidence is small, 1 mm over a line length of 200 m, and recovers completely when the well is not pumped.

Resurveys of alignment arrays across the San Andreas fault near Gorman and across the Nadeau fault near Palmdale have not revealed any surface displacements whatsoever.

Surveys of trilateration arrays have merely established reproducibility and sensitivity of the surveying instruments and techniques and have not revealed any crustal movements.

<u>Reports</u>

Sylvester, A. G., T. Rockwell and N. Riggs, 1979, Slow nearfield vertical deformation across California faults. EOS 60 (18) p. 316-317.

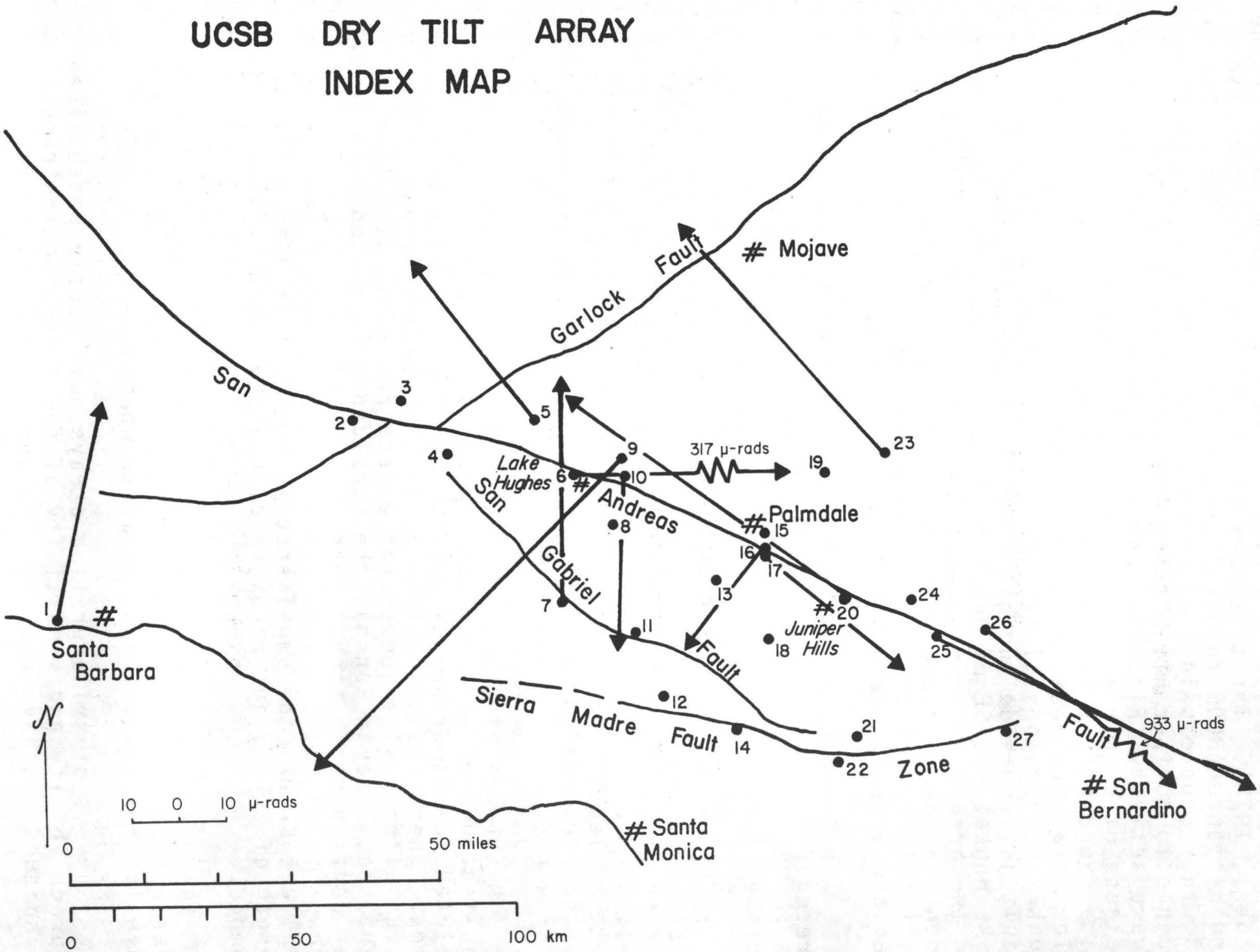

Figure 1. Map showing tilt vectors of anomalous tilts from November 1977 to August 1978.

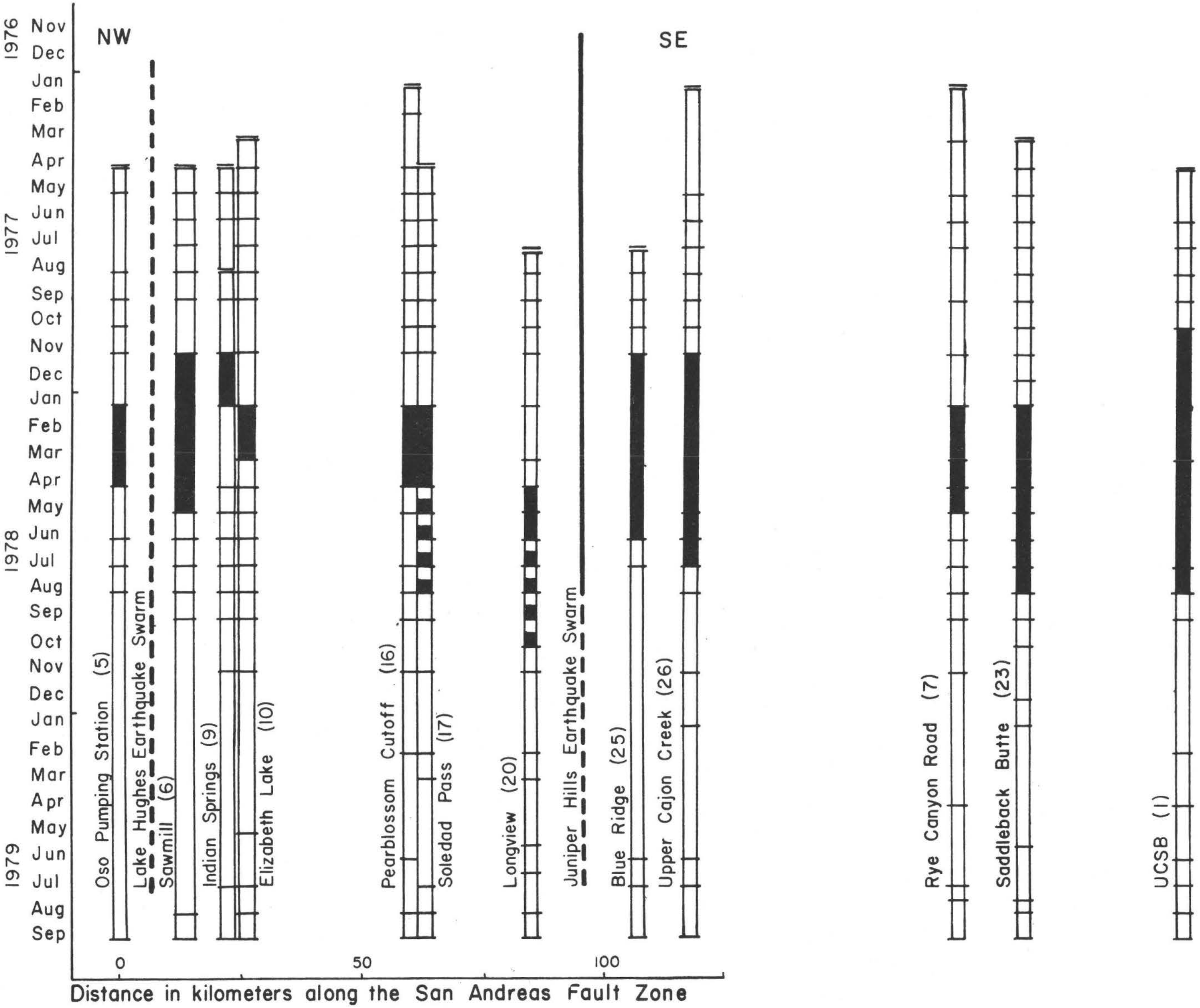

Figure 2. Time - history diagram for 12 dry tilt arrays. Arrays from Oso to Upper Cajon Creek are arranged with respect to distance along the San Andreas fault. Rye Canyon, Saddleback Butte and UCSB are far from the fault and are shown for comparison. Solid parts of parts indicate time periods during which the tilt anomalies occurred. Short horizontal lines across each array bar indicate resurveys. Solid and dashed lines indicate time periods of earthquake swarms at Lake Hughes and Juniper Hills.

Development of a Portable Absolute Gravimeter with Microgal Sensitivity

by James E. Faller
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Final Report Summary

A major effort is underway to develop a highly portable absolute gravimeter having an accuracy of 3 μgal or better. Significant progress to this end has been made. At present, our electronics limit the accuracy which we can obtain to 2 parts in 10^7 or about 200 μgal. The value obtained at this accuracy limit, however, agrees with the value established for our site via a relative tie to an absolute gravity site in Denver. It is expected that by up-grading our electronics (utilizing a timing unit that is now commercially available) and also by utilizing a NBS-designed I_2 stabilized laser, we will be able to improve the accuracy of this instrument to a few parts in 10^9.

The instrument consists of basically four parts: a drag free dropping chamber, an isolating spring, a stabilized laser, and the necessary timing electronics. The size and weight of these units is such that the apparatus can be easily handled and assembled by a single person. The expected measurement time required at any given site is about one hour. We believe field use of this new instrument should significantly advance the study of tectonic processes.

Continuous Gravity Measurements in the Region of the Palmdale Uplift

P.B.4.

USDI-14-08-0001-G-374

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Goals

1. The purpose of this project is to obtain a continuous record of gravity from a superconducting gravimeter at a fixed site in the region of the Palmdale uplift. This record would be used to detect temporal gravity changes associated with crustal deformation and uplift. It would also provide a direct connection between gravity surveys at different points in time in the Palmdale area.

Investigations

1. A superconducting gravimeter was installed near the 2800 foot contour northwest of the Lytle Creek Ranger Station in July 1978. Digital signals from the gravimeter and a barometer are recorded continuously in the field and can be transmitted when desired to our laboratory by telephone. Tidal subtraction for a ten month record from 28 November 1978 to 19 October 1979 was performed by least squares fitting and subtracting both a theoretical solid earth tide and sinusoids at the frequencies of the ten largest ocean tides.

2. Preliminary analysis of the resulting residual for gravity variations due to groundwater effects and possible uplift has been attempted.

Results

1. The Lytle Creek residual gravity record (Figure 1) shows long and short term variations from 50 to 100 μgal. These variations are far greater than those from the five superconducting instruments operating at other sites. For example, a residual gravity record from Boulder, Colorado showed variations of less than 10 μgal for a period of 57 days. The variations observed at Lytle Creek can be separated into three categories: rainstorm-related effects, diurnal variations, and secular (long-term) changes.

2. All of the rainstorm related effects take place in the first six months data and are replotted in Figure 2a. Also shown in Figures 2b and 2c are the daily rainfall data from the ranger station at Lytle Creek and the gage height of Lytle Creek recorded about 3 km downstream of our instrument. The storm-related effects display two characteristics. In all cases one sees a rapid short-term increase in gravity with its onset highly correlated to the local rainfall. This is followed by a slower decrease in gravity over a several day period. With the exception of two cases the increase and decrease in gravity are equal so that no net change is observed. However, in the two cases corresponding to the first and third major rainstorms of the season, one also observes a persistent level change.

3. Since a permanent tilt of the vault can be eliminated as a source of the level changes, the only non-geophysical possibility is that these changes are

due to some instrumental malfunction. Evidence which suggests that this might be the case is that there were two instrumental offsets triggered during transfers of liquid helium. They followed the rainstorms by only a few days and were of just such signs and magnitudes so as to preserve the pre-rainstorm baseline to within 10-20 μgal. At present we know of no mechanism which could lead to a connection between the offset and the rainstorm effect. Consequently we present the data with persistent level changes (i.e., known instrumental offsets removed) even though they appear to be an instrumental artifact.

4. These level changes could conceivably be explained by local changes in the watertable. Our site is at the north end of a gravel-filled basin which covers an area of roughly 10^6 m^2. The watershed draining directly into this basin is about 10^7 m^2, while the watershed for the creek upstream from our location is around 10^8 m^2. Extrapolation of the slope of the adjacent mountains into the center of the local basin suggests that it could be in excess of 100 m in depth. For the two rainstorms in question approximately 15 cm of rain fell per storm which would make 10^6 m^3 of water available from the local watershed and 10^7 m^3 from the entire Lytle Creek watershed. If we assume that the gravel basin near the gravimeter filled with water during the two rainstorms, and that the basin can be modelled as a semi-infinite plane, the gravitational increase would be 0.21 μgal/cm. Therefore, to produce a 100 μgal signal, a half-sheet of about 4.8 m of water is required. Assuming the entire 10^6 m^2 basin gained this much water, 4.8×10^6 m^3 of water is necessary. In this case 30% of the water from the entire Lytle Creek watershed is required, and the portion of the watershed local to the gravel-filled basin is insufficient. In addition, assuming a 15% storage coefficient, a 32 m rise in the groundwater would be necessary. Although an increase in watertable of 150 feet was observed in a well 15 km downstream in 1978, the increase took nearly the entire year in contrast to the gravity changes we observe in a few days. Factors such as proximity to the stream, distance from the watershed, and properties of local landfill, could possibly explain the difference in time scale at the two locations.

5. The model of a basin filling with water also explains the behavior of Lytle Creek. Early in the rainy season, when the basin is nearly empty, one would expect the water to fill the underground basin rather than run off in the creek. This would suggest that one should see a persistent change in gravity and no long-term change in the creek height. Later in the season, after the basin has filled, one would expect most of the water to run off, causing only temporary perturbation in gravity but a persisting change in the creek height. This is, in fact, what one sees in Figure 2c.

6. The gravity survey data of John Fett measured between Hemet and Lytle Creek does not show these persistent changes on the 100 μgal level. Since Fett's survey site at Lytle Creek is some 100 m distant from our site, it is possible that a very local hydrological model could explain the difference. However, the model explicated above is not sufficiently local. Thus we conclude that the persistent changes in gravity are most likely instrumental in origin, even though at this time we cannot propose any instrumental mechanism for the effect.

7. The remaining short-term storm related effects consist of a temporary increase in the strength of gravity, which decays back to the previous level within several days. In the absence of continuous monitoring of the tilt of our vault, tilt remains a possible cause of these variations. The pressure

exerted by the water in the topsoil on the sides of the vault can be considerable and the pressure is asymmetric since the vault is half-buried at the base of a small hill. Thus the vault could be tilted downhill as the ground becomes wetter and heavier, and could then relax back as the ground dries out. We are currently deploying an automatic leveling system at the site which, by keeping the instrument vertically aligned, will entirely eliminate tilt as an unknown.

8. The last effect to be discussed is also potentially the most interesting. If one excludes the data containing the persistent level changes and only considers the data beginning around 1 February 1979 to 19 October 1979, a decrease in gravity of 40 μgal is observed. This change cannot be accounted for by tilt since it is of the wrong sign and since periodic relevelings of the instrument preclude such long-term effects. The most likely geophysical explanations are crustal uplift or groundwater depletion, or a combination of both. In the future we intend to monitor the depth of water in a nearby well in order to obtain quantitative estimates of the magnitude of the groundwater effects on gravity. This in turn should lead to an estimate of the possible uplift or subsidence occuring in the region around Lytle Creek.

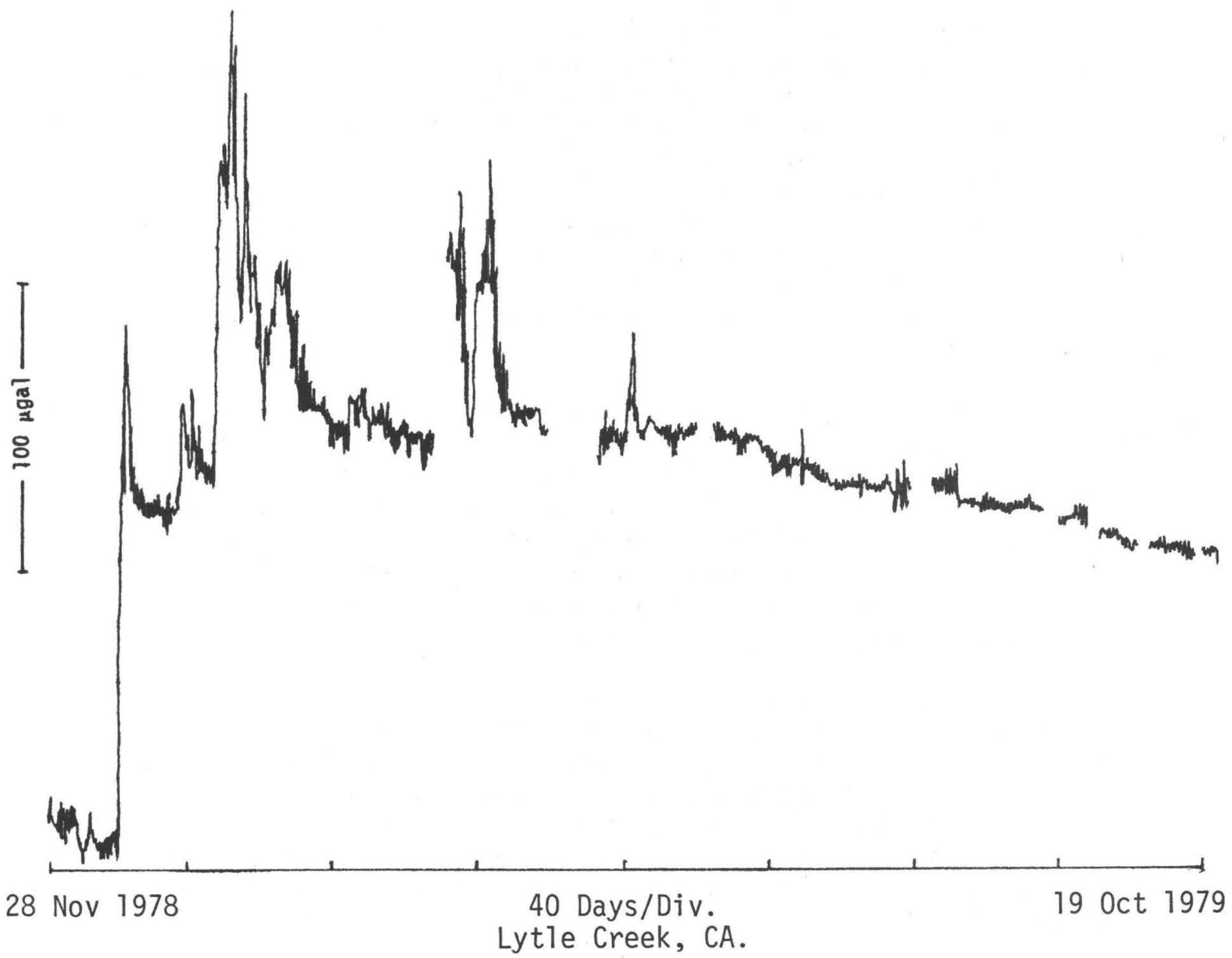

Figure 1

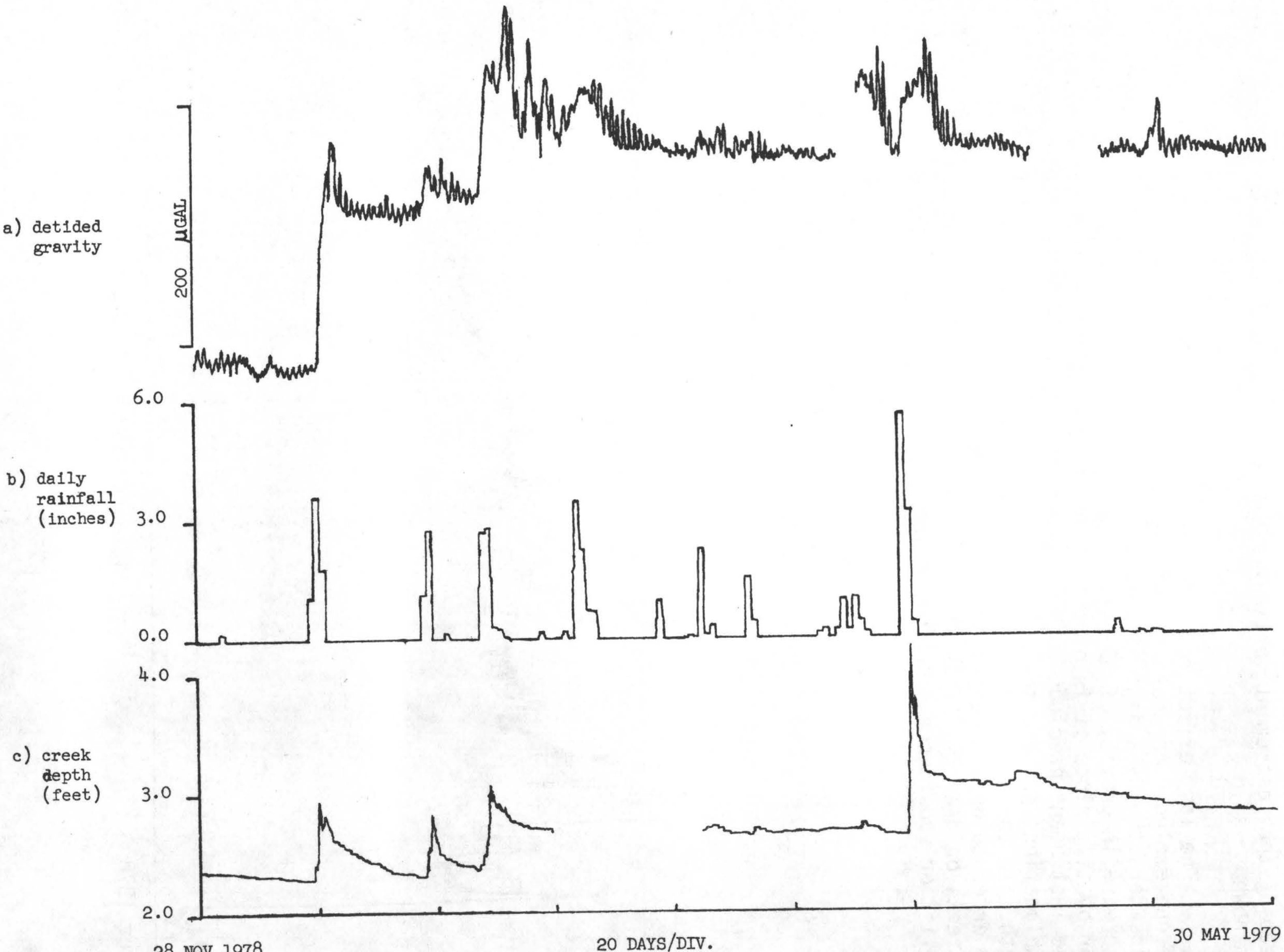

FIGURE 2. LYTLE CREEK, CA.

Causes of Gravity Change in the Upper Mississippi Embayment

14-08-0001-G-489

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A network of 18 precision gravity stations was first established in the upper Mississippi Embayment in November 1975 and reoccuppied bimonthly from September 1976 through June 1978 (Figure 1). Two LaCoste-Romberg Model G meters, numbers 409 and 226 were used in the study. The network is composed of an east-west line extending from the Ozark Dome to the Nashville Dome and from the center of the Illinois Basin to Memphis, Tennessee.

Time-trend analyses of the differences in gravity (Δg) between adjacent stations indicate no significant variations in Δg away from the Mississippi River; however, Δg does vary significantly between stations near the river (Figure 2). The maximum change in Δg is 110 μgals; whereas, the mean standard deviation of Δg is 15 μgals.

Gravity effects which would be produced by ground water levels, as determined from water wells, precipitation, and estimates of changes in bank storage, are an order of magnitude less than the observed change in Δg. It is also unlikely that a dilating crust might provide the explanation for fluctuating Δg at stations the length of the river. The average correlation coefficient between gravity change and river stage is +0.8; therefore it is concluded that river load produces elevation changes that are causing variations in Δg. Elevation changes are accounted for by change in water mass which produces elastic deformation of sediments beneath the river. Vertical deformation of about 0.35 m is derived from the observed Δg. It is assumed that the most compressible geologic unit underlying the river at Cairo, Illinois, where the largest variations are observed, is the Pleistocene and Holocene alluvium. If all of the deformation occurs in the alluvium a compressibility of 4.15 mb^{-1} is derived which is a reasonable value for unconsolidated sand.

Deformation of sediments produces seasonal change in pore water pressure. Increasing stage, which would suggest increasing pore pressure, also corresponds with an increase in energy released by earthquakes; however, maximum earthquake energy release occurs about three months after maximum stage. If high pore pressures trigger earthquakes beneath the river, migration of anomalously high pressure must travel at rates of 50 to 150 meters per day along fault zones to reach focal depths of five to fifteen kilometers.

From this study it has been found that two LaCoste-Romberg gravimeters, read in tandem, and the careful handling and reading technique used throughout the survey, can result in the attainment of gravity differences between stations 30 to 40 km apart having an average standard deviation of .015 mgals. This precision when compared to observed changes in gravity is adequate. It is therefore concluded that the changes observed in these surveys are real and that the changes are caused by tilting of the land surface near the river. The observed tilting raises serious questions as to the accuracy of long term tilt measurements calculated by other authors. The cyclic variations in elevation along the river would result in erroneous conclusions being derived from periodic leveling measurements made in the vicinity of the Mississippi River.

The model proposed here to explain observed changes in gravity with changing river stage adds credence to those studies that suggest that seismicity in the embayment may be triggered by changing river stage. The present study indicates that changing river stage and the resulting compression of the saturated sediments that underlie the river may aid in migration of pore water pressure downward along fractures, reducing effective stresses and allowing movement along faults.

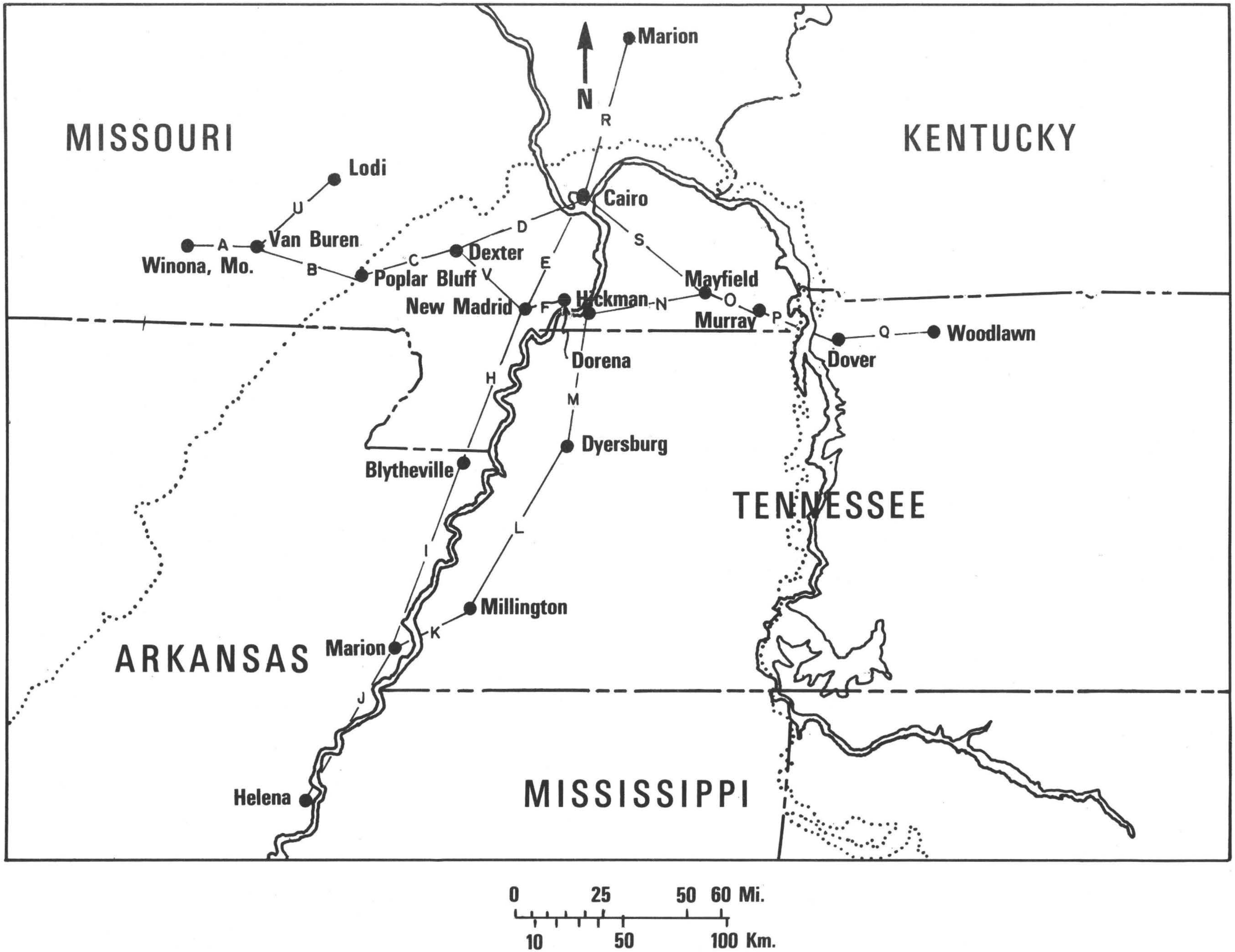
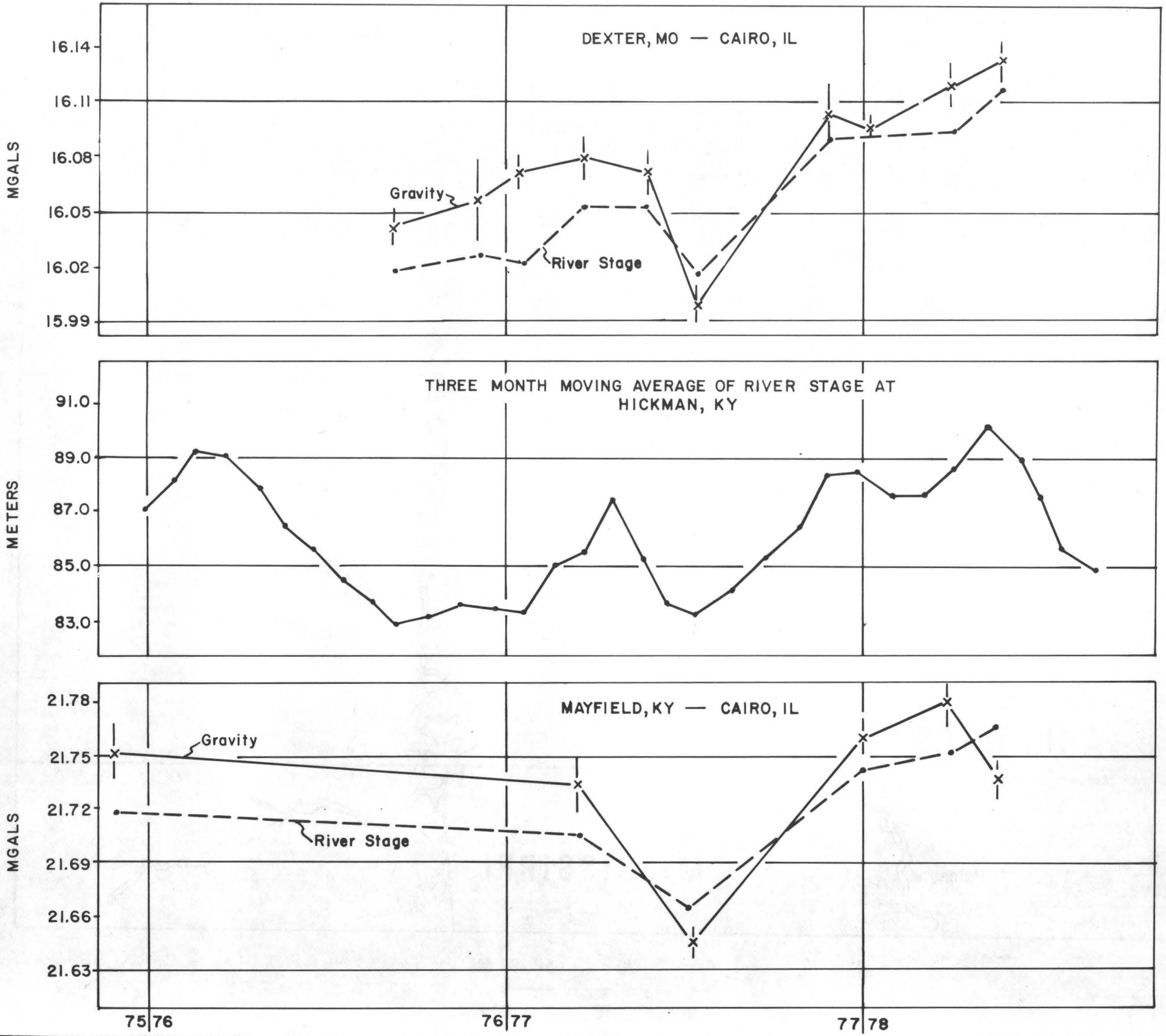


FIGURE 1. PRECISION GRAVITY BASE STATION NETWORK IN THE NORTHERN MISSISSIPPI EMBAYMENT


DEXTER, MO — CAIRO, IL
MGALS
16.14
16.11
16.08
16.05
16.02
15.99
Gravity
River Stage
THREE MONTH MOVING AVERAGE OF RIVER STAGE AT HICKMAN, KY
METERS
91.0
89.0
87.0
85.0
83.0
MAYFIELD, KY — CAIRO, IL
MGALS
21.78
21.75
21.72
21.69
21.66
21.63
Gravity
River Stage
75|76
76|77
77|78

P.B.4.

NOISE REDUCTION TECHNIQUES FOR TECTONOMAGNETIC STUDIES

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Grant No. 14-08-0001-G-519

May 15, 1979

Work on "Noise Reduction Techniques for Tectonomagnetic Studies" will continue through 30 June, 1979. A final technical report will be presented after that date. This report is a summary of work completed from 15 September 1978 through 15 March 1979.

I. Geomagnetic field measurements and noise reduction techniques in Colorado.

Self-calibrating rubidium magnetometers (SCRs) accurate to 0.01 γ rms (Ware and Bender, 1978) were deployed in Colorado to investigate geomagnetic problems. Data were recorded using the collinear array of 3 SCRs shown in Fig. 1. The simple differences TM-GB and GB-ER recorded during early spring of 1978 are shown in Fig. 2. Also shown is the residual of TM-GB after correlations with GB-ER were removed using a frequency dependent transfer function (Ware, 1979). This method is called the scalar transfer function method, since vector field information is not used. Variations in the scalar transfer function residual were not found to correlate with magnetic field component changes measured at the Boulder Magnetic Observatory at Table Mountain (TM). The sources of the remaining variations in the residual TM-GB are not known. However, the 0.03 γ rms residual of TM-GB demonstrates the long term stability of the SCRs and the local geomagnetic field over distances of 12 km. Also demonstrated is the possibility of detecting magnetic events at levels substantially below the 0.25 γ least count uncertainty of proton magnetometers currently used for seismomagnetic research in California.

II. Analysis of proton data from California.

Simple differencing (Smith <u>et al</u>., 1978) and vector transfer function methods (Poehls and Jackson, 1978) have been used for noise reduction of proton magnetometer data from California. However, the variation of residuals calculated using these techniques is reported to be considerably larger than the 0.25 γ least count uncertainty of the proton magnetometers. The simple differences SJ-HA and LE-HA, calculated from central California proton data, are shown in Fig. 3. Also shown is the residual of SJ-HA after correlations with LE-HA were removed using the scalar transfer function method. The locations of these sites are shown in Fig. 4. Note that the 0.15 γ rms residual of SJ-HA is smaller than the 0.25 γ least count uncertainty of the proton instruments. This result demonstrates the stability of proton magnetometers and the local geomagnetic field at levels below 0.25γ rms for some sites in central California. The sources of the remaining variations in the residual SJ-HA are not known. However, in a preliminary analysis the residual variations were not found to correlate with magnetic field component changes measured at the Castle Rock Magnetic Observatory. This fact implies that the residual variations of SJ-HA are not dominated by susceptibility differences, induced currents, or magnetic field direction differences between sites SJ and HA. Instead, the residual is apparently dominated by instrumental or other unknown effects. A search for correlations between the proton simple differences and fluxgate component data measured at nearby sites (Ernest Iufer, NASA) is also in progress.

Evidence for noise generated by tidal ocean currents has been discovered in the proton data from California. Examination of SJ-HA and LE-HA during the first 6 months of 1975 revealed recurrent semidiurnal variations ranging up to 2γ, modulated at a period of 14 days. This modulation is evident in Fig. 3 for SJ-HA and LE-HA, but it is not evident in SJ-HA (residual). Simple differences between sites more removed from the coast such as LE-BV show a diurnal structure characteristic of Solar quiet variations. The diurnal variations for LE-BV are not modulated. Thus, semidiurnal variations, modulated at 14 day (tidal) periods, are dominant only at sites near the coast. In addition, Fourier analysis of SJ-HA and LG-GD for the period 29 August through 19 September, 1978, reveals 3 times more power in SJ-HA at 24, 12, and 8 hour periods. This evidence suggests the existence of magnetic variations ranging up to 2γ due to ocean tidal currents for some sites near the coast. A similar effect was reported near the English channel (Osgood, 1970). It was also found that the semidiurnal power of SJ-HA was reduced by a factor of 3 in the residual shown in Fig. 3, which demonstrates that the scalar transfer function method can substantially reduce tidal noise.

Other methods of reducing the ocean current noise are being sought. These include the search for correlations between simple magnetic difference variations and tide gauge records, gravimeter records and tidal current predictions. An attempt to filter the magnetic data at dominant tidal frequencies is also in progress.

III. Modification of SCR

Previous versions of the SCR combined a self-oscillating rubidium magnetometer (SOM) with a narrow line rubidium sensor (NLS) which resolves the Zeeman magnetic sublevels. The SOM has high signal to noise, but is subject to long term drift ranging up to several γ. The SOM was stabilized (to ∿0.01γ rms) by the NLS. The NLS has poor signal to noise. The combined benefits of high signal to noise and 0.01γ stability are thus obtained in the SCR (Allen and Bender, 1972).

However, an unfortunate characteristic of the SOM (which oscillates near 390 kHz in the geomagnetic field near Boulder) is its sensitivity to changes in rf ground. These changes are difficult to avoid in a field instrument which uses 50 meters of cable to separate the sensor from the control electronics. To eliminate this problem, a phase locked loop was designed to replace the old self oscillator system. Functionally, the SOM is changed into a phase shifter driven by a voltage controlled oscillator. Sensitivity to changes in rf ground are greatly reduced in this new system. An additional advantage is simplified rf tuning over a broad range of frequencies (or equivalently, magnetic field values).

References

1. Allen, J. H., and P. L. Bender, Narrow line rubidium magnetometer for high accuracy field measurements, J. Geomag. Geoelectr. 24, 105 (1972).

2. Osgood, C., Design and use of a gradiometer connected rubidium magnetometer, Revue de Physique Appliquée 5, 113 (1970).

3. Poehls, K. A., and D. D. Jackson, Tectonomagnetic event detection using empirical transfer functions, J. Geophys. Res. 83, 4933 (1978).

4. Smith, B. E., M. J. S. Johnston, and R. O. Burford, Local variations in magnetic fields, long-term changes in creep rate, and local earthquakes along the San Andreas fault in central California, J. Geomag. Geoelectr., 1978 (in press).

5. Ware, R. H., Improved techniques for reducing geomagnetic noise, accepted for publication in J. Geophys. Res., 1979.

6. Ware, R. H., and P. L. Bender, Noise reduction techniques for use in determining local geomagnetic field changes, J. Geomag. Geoelectr., 30, 1 (1978).

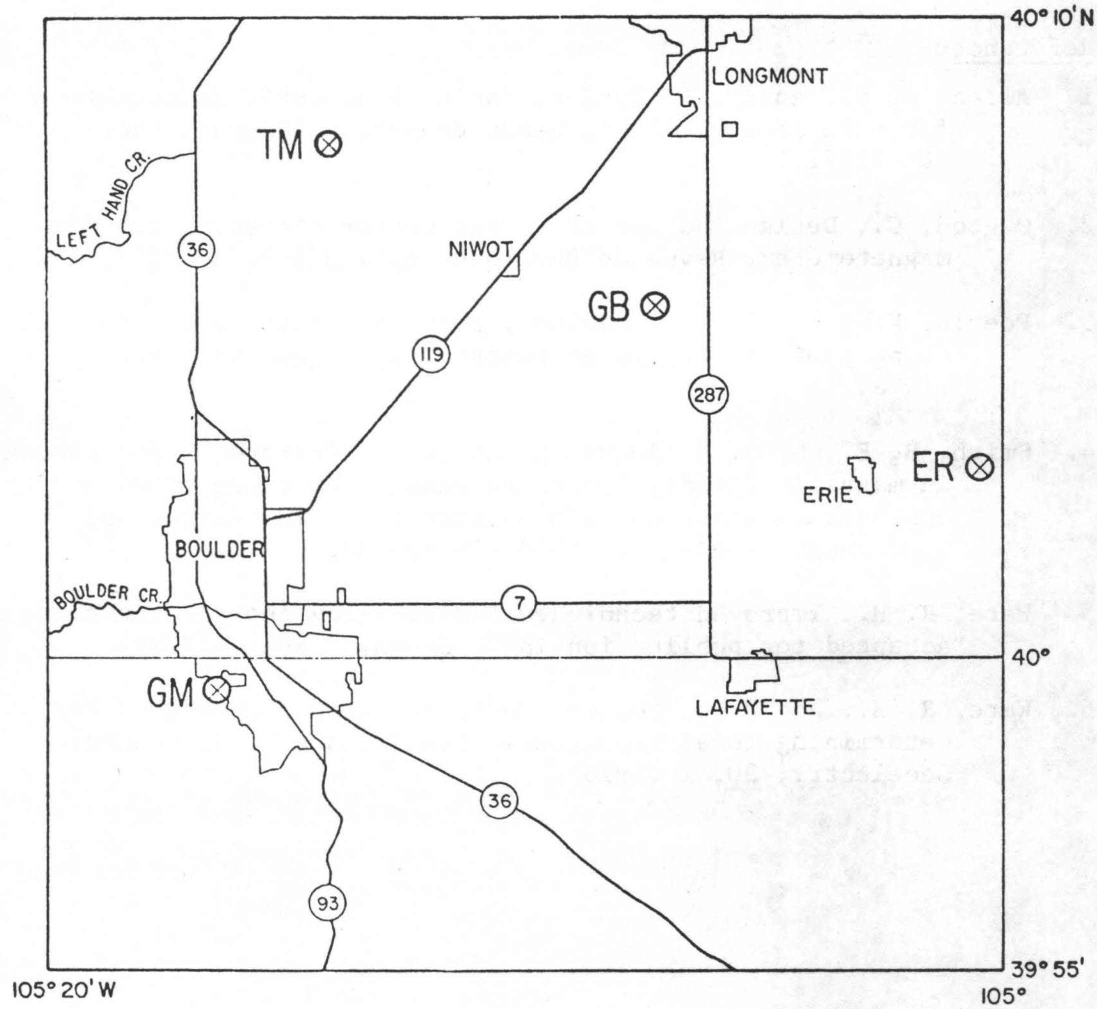

Figure 1. Locations of narrow line rubidium magnetometer sites in Colorado.

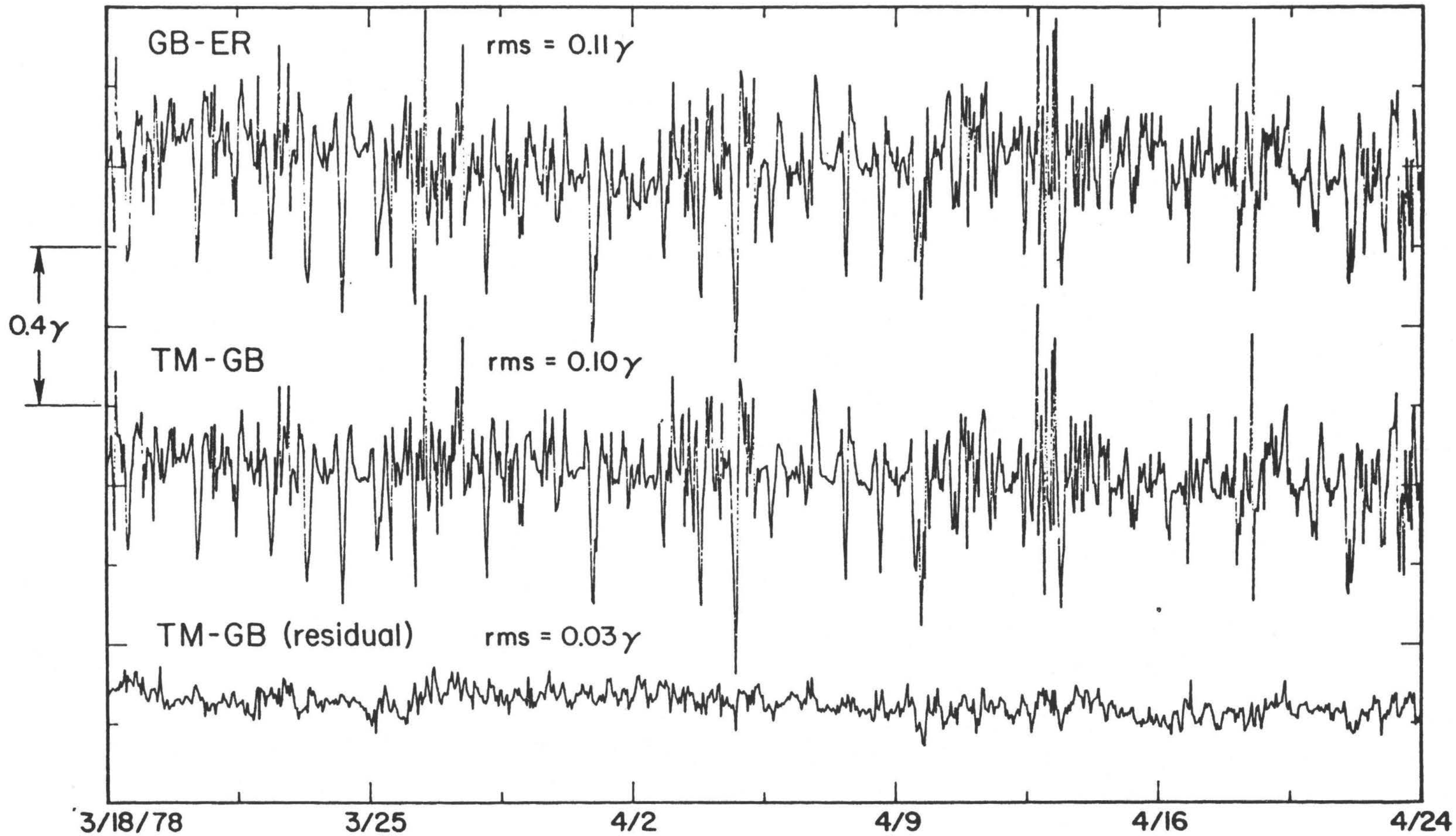

Figure 2. The top two curves are simple differences of self-calibrating rubidium magnetometer data from Colorado. The bottom curve is the residual which was calculated using a transfer function between the top two curves. One hour averages are shown.

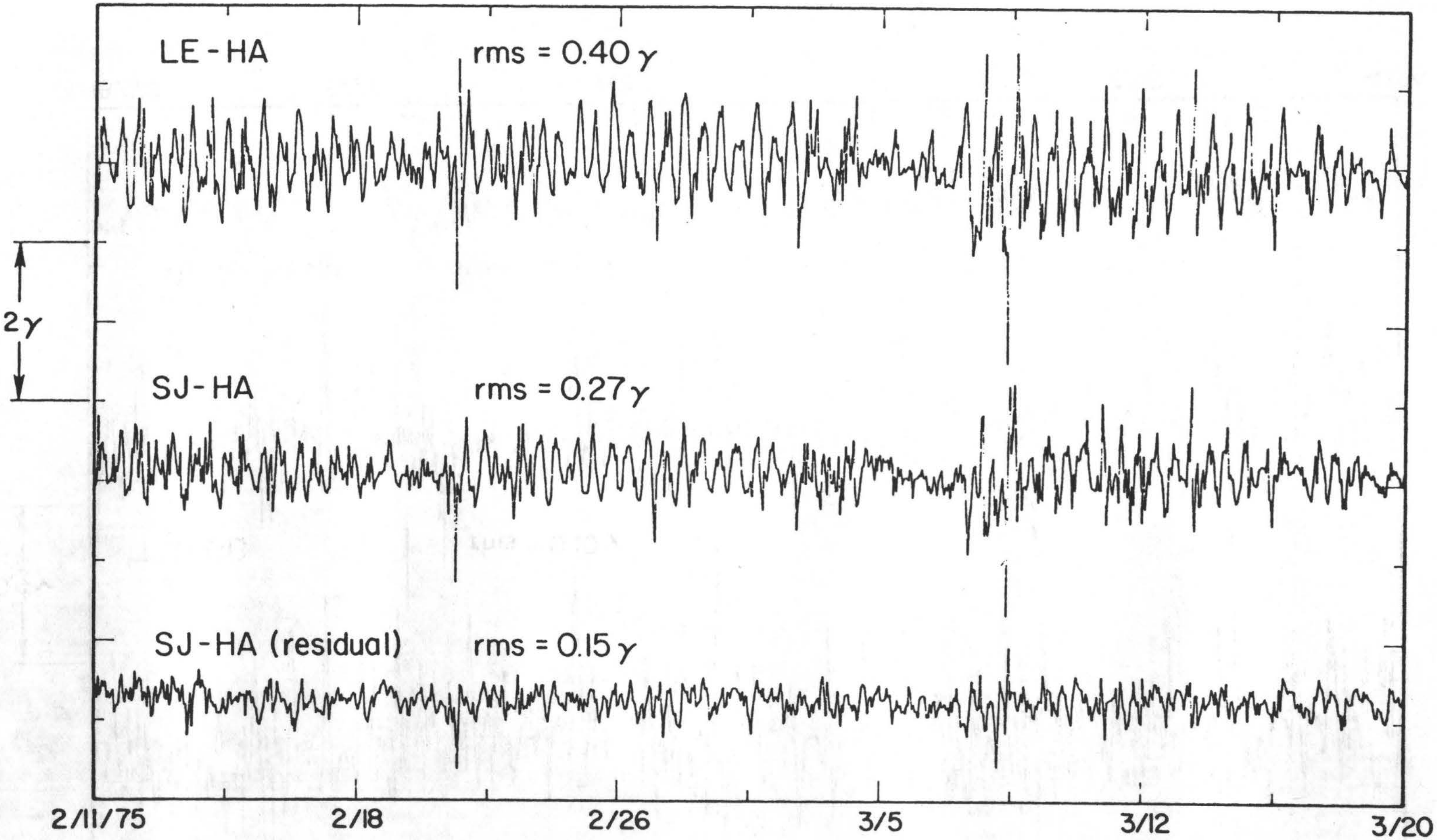

Figure 3. The top two curves are simple differences of USGS proton magnetometer data from central California. The bottom curve is the residual which was calculated using a transfer function between the top two curves. One hour averages are shown.

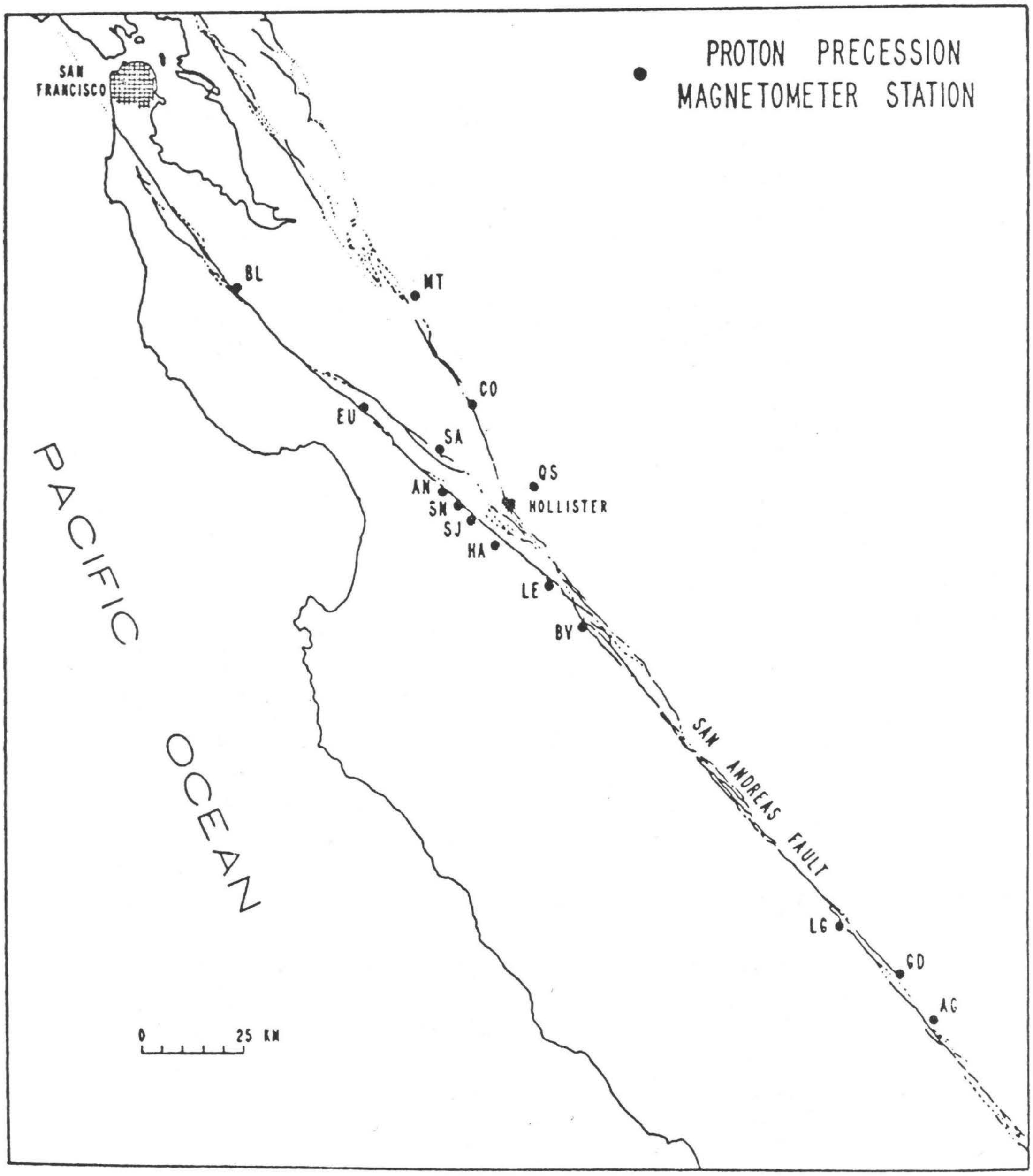

Figure 4. Locations of proton magnetometer sites in central California [Johnston, 1978].

Magnetometer Array at Liebre Mountain

8-0001-17688

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Investigations

1. We have continued to operate three proton precession magnetometers at 5-km spacings near Liebre Mountain.

2. We have operated a site for magnetometer testing near San Gabriel Canyon.

3. During the aftershock sequence of the Coyote Lake earthquake, we operated two continuous recording magnetometers, and carried out repeated leapfrog surveys using a pair of portable magnetometers.

4. We have carried out a laboratory program to identify and remove sources of noise in proton precession magnetometers.

Results

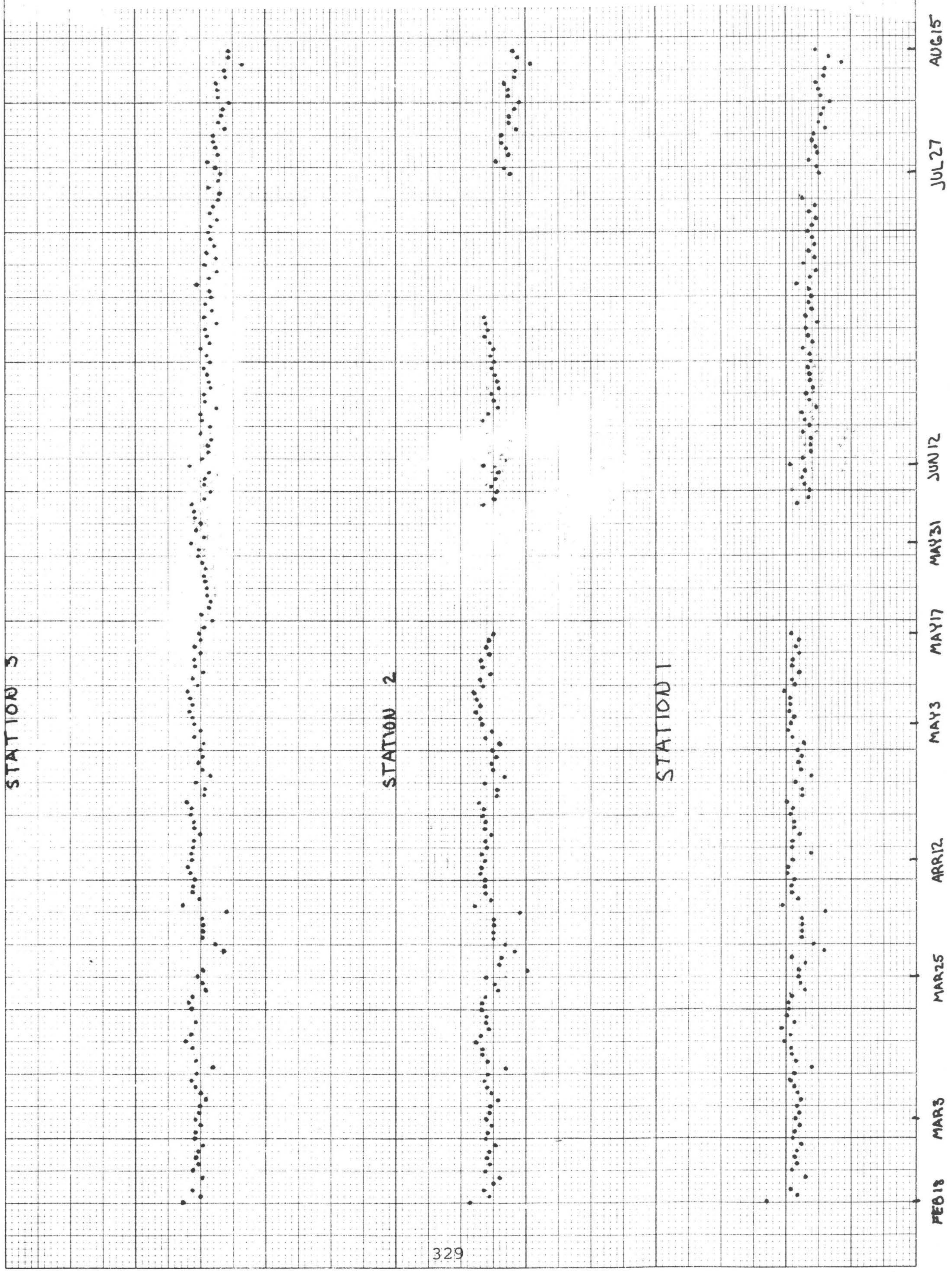
1. Data return from Liebre Mountain has been consistent (Figure 1), and high quality (Figure 2). Standard deviations of hourly averages of station differences range from 0.3 to 0.5 for four-month intervals. Standard deviations are reducible to about 0.1 nT (Figure 3) by using vector data from our San Gabriel Canyon test array.

2. Simultaneous operation of a vector fluxgate magnetometer and a scalar proton precession magnetometer indicates that the field aligned component of the fluxgate has a temperature sensitivity of 2nT/deg C, numerically correctable to 0.2 nT/deg C. The test was interrupted for a period of two months so that the proton precession instruments could be operated at the site of the Coyote Lake earthquake. We now have two proton precession magnetometers and one fluxgate operating within 10 m of one another. We expect to install an additional fluxgate within 6 weeks. Prof. Tom Henyey of USC expects to install a cryogenic vector magnetometer as soon as it is delivered by the manufacturer, hopefully within 6 weeks.

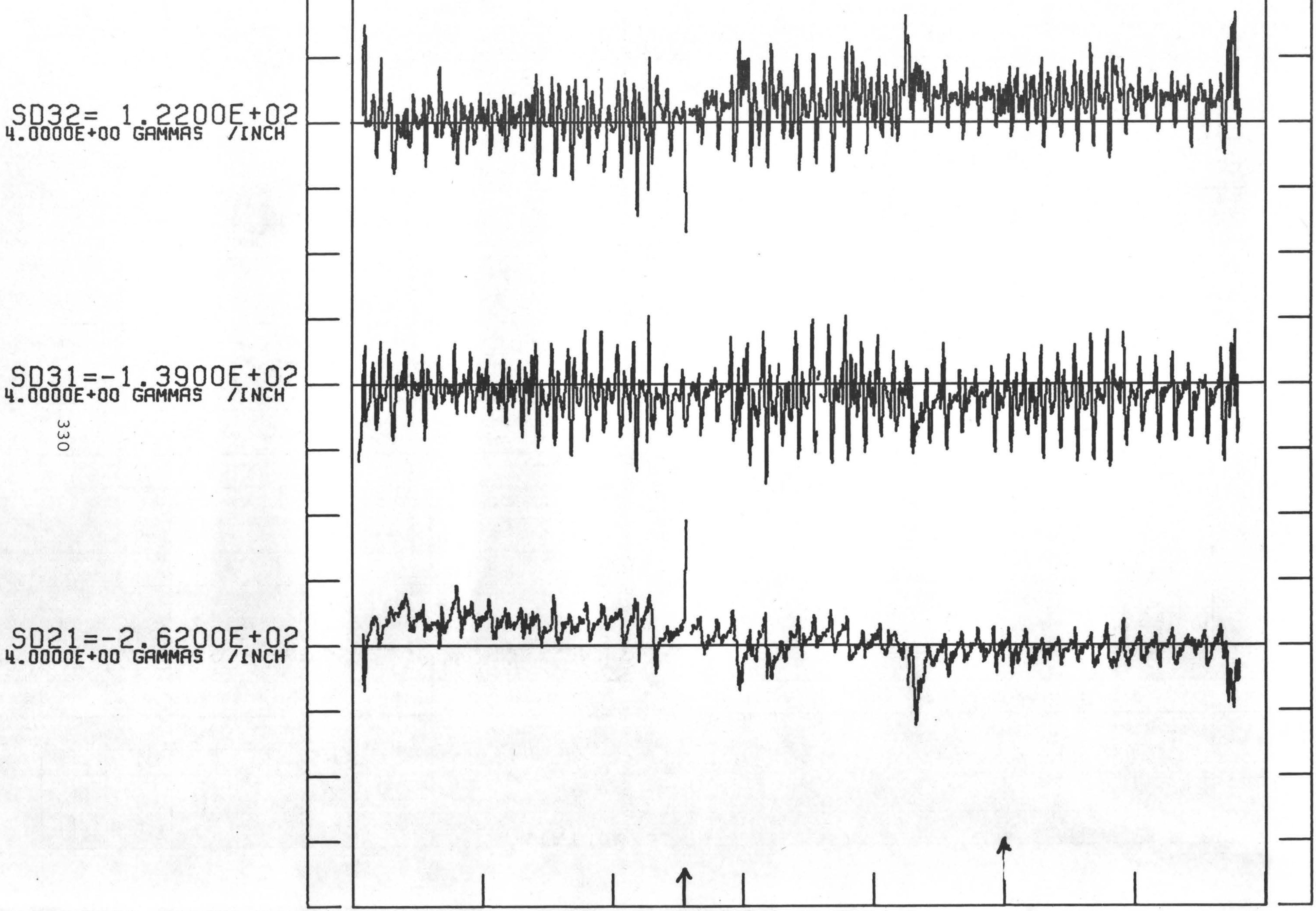
3. No temporal magnetic anomalies greater than 0.5 nT, either coseismic or preseismic, accompanied any of the aftershocks of the Coyote Lake earthquake after 10 July 1979.

4. We have experimented with various elements of the magnetometer, developing procedures to test for proper operation. These developments lead to several changes in our field instruments including decoupling of power supplies, elimination of ground loops, upgrading of integrated circuits, and fine tuning of instruments for the specific sites. Throughout the program we have used spectral analysis to characterize the instrument performance.

1. Plot of daily average magnetic field values for Liebre Mountain array. Data quality remains consistent up to present.



2. Hourly averages of station differences for 55-day period. Prior editing has removed approximately 2-3% of the one-minute samples. Baseline offsets of about one nT in all curves correspond to instrument modifications on 15 Aug 79. Apparent drift of 0.5 nT in lower curve after 15 Aug 79 is unexplained.



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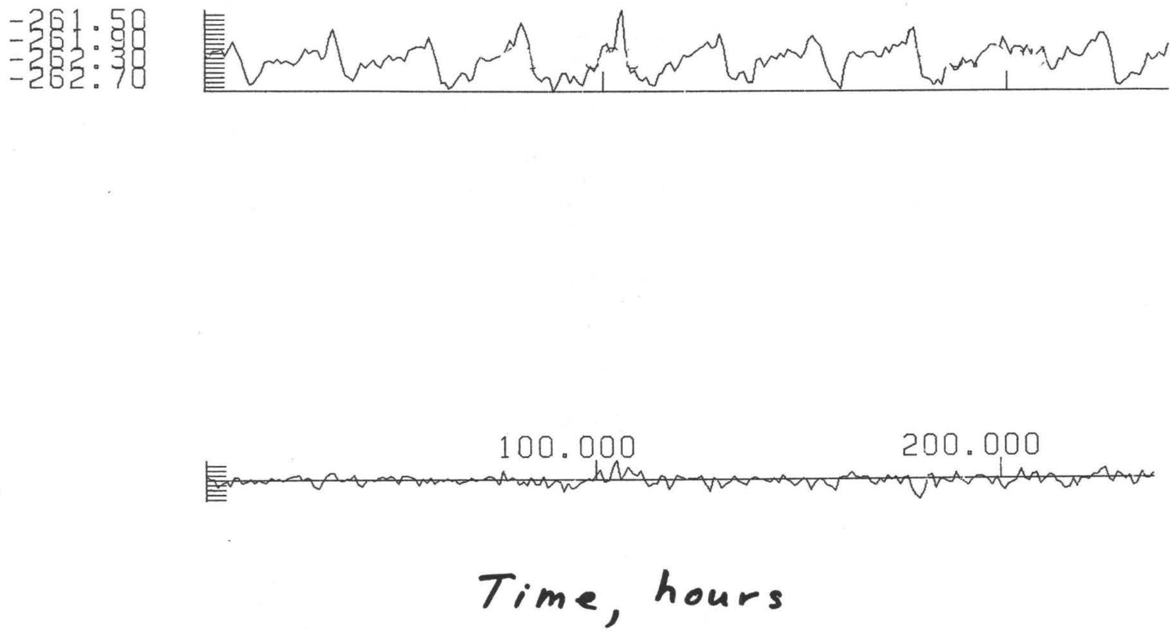

3. Hourly averages of station differences for period 7 Sep to 17 Sep 79. Station differences have been reduced using 12-parameter Weiner prediction filter based on observed vector field at San Gabriel Canyon. Upper trace: before filtering. Lower trace: after filtering. Scale 4nT/inch.

INVESTIGATION OF THE SOUTHERN CALIFORNIA UPLIFT USING DIFFERENTIAL MAGNETIC FIELD MONITORING OF TECTONIC STRESS

Contract 14-08-0001-17681

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Investigations

Magnetic field measurements, initiated in 1973, are being taken at 43 field locations in southern California for the purpose of monitoring tectonic stress change. A two dimensional array of sites extends from near Gorman on the NW to the Indio Hills and Anza Valley on the SE. A loop of sites also extends around the north side of the San Bernardino Mountains.

Instruments are not permanently placed in the field, but benchmark-like sensor supports are buried in concrete to permit precise relocation from survey to survey. Readings are taken at two adjacent sites over a simultaneous, ten-minute interval of time and the mean values of the data sets are computed and differenced. The time variation of this difference of means becomes, via the piezomagnetic effect, an indicator of tectonic stress change in the earth's crust beneath the observations. Three separate surveys were completed across the entire array between June 1978 and July 1979. The next survey will be conducted in December 1979.

Results

From June 1978 to April 1979 the crustal stress changed by modest amounts. In contrast, the interval from April 1979 to July 1979 was a period of considerably greater stress change. An analysis of error indicates that a rate of change for a site-pair of 1/2 gamma or greater per month is significant. Thus, the following areas, defined by contoured values on a map for the three month period prior to July 1979, are considered to have anomalously high rates of change(Fig.1).

Summary Contract 17681, pg. 2

Results (cont'd)

a) One gamma or greater per month

(1) Wrightwood
(2) Cajon Pass
(3) Lucerne Valley
(4) Desert Hot Springs

b) Three-fourth to one gamma per month

(1) Mojave (town)
(2) San Fernando
(3) Palmdale
(4) Landers
(5) Anza Valley

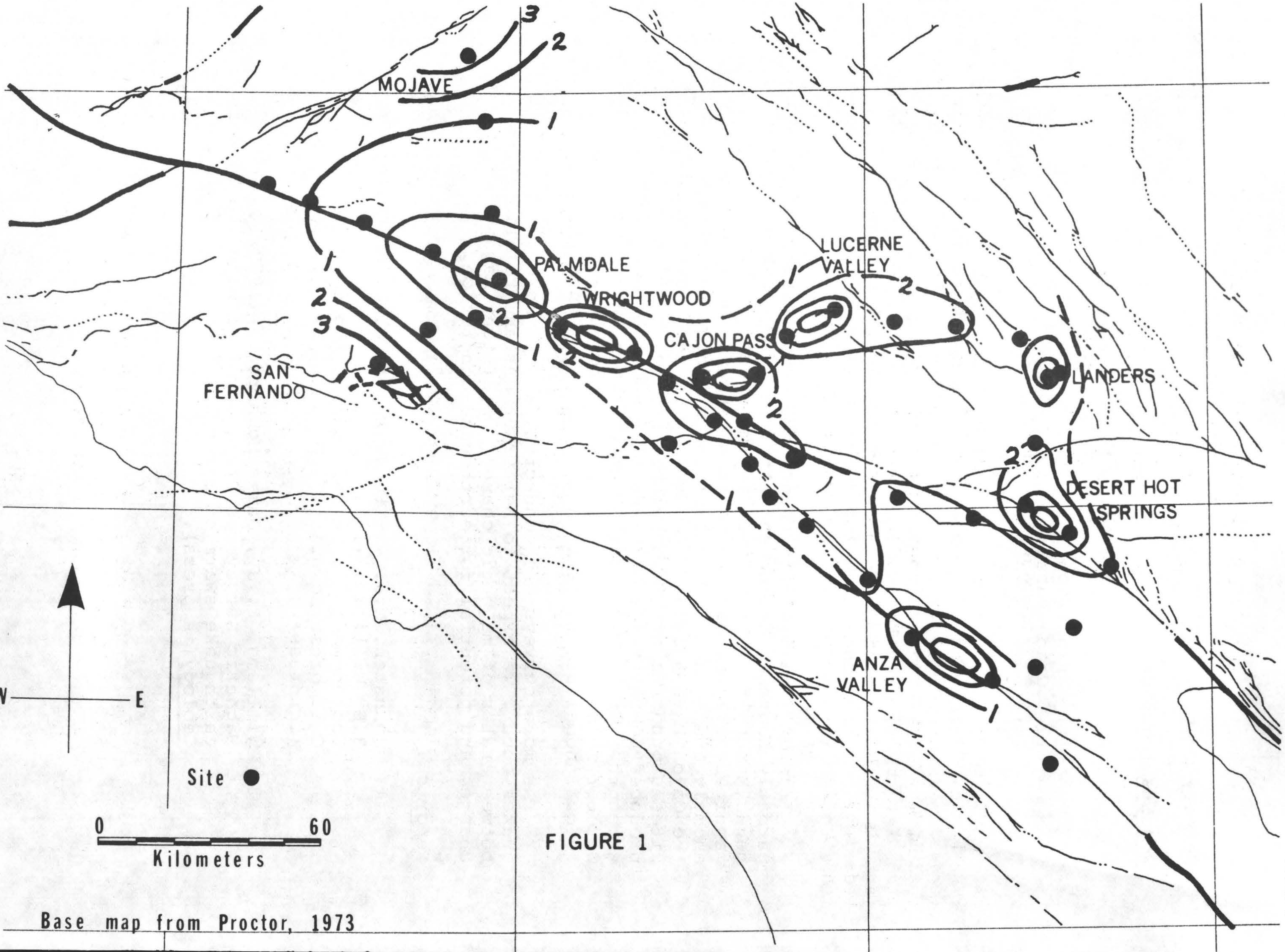
Most of the magnetic change observed at Landers apparently happened during and after the earthquakes that began March 15, 1979. Since the maps were plotted, a magnitude 3.7 earthquake occurred beneath the Wrightwood anomaly and a magnitude 4.1 earthquake occurred within the Cajon Pass anomaly. However, a recent resurvey of sites around the preliminary epicenter of the 4.1 event produced no reversals of trend of the magnetic field strength. It is not apparent at this time whether the October 15 magnitude 6.4 Calexico earthquake was related to our anomalies at Desert Hot Springs and Anza Valley.

As more surveys are conducted, and as more earthquakes occur, we expect to better understand relationships between rates of magnetic change, persistent magnetic change, and potential for earthquake generation.

Reports

1. Johnston, M.J.S. , F. J. Williams, J. McWhirter, B.E. Williams, (1979)
Tectonomagnetic anomaly during the southern California downwarp. Jour. Geophysical Research (in press).

2. Williams, F. J., James McWhirter, (1979).
Magnetic survey results associated with the Landers earthquake swarm of March 15, 1979. California Geology (in press).



MOJAVE
PALMDALE
WRIGHTWOOD
LUCERNE VALLEY
CAJON PASS
SAN FERNANDO
LANDERS
DESERT HOT SPRINGS
ANZA VALLEY
1
2
3
W
E
Site
0
60
Kilometers
Base map from Proctor, 1973

FIGURE 1

Electrical Conductivity Studies on the San Andreas Fault South of Hollister, CA

14-08-0001-17763

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Controlled source electromagnetic studies of the San Andreas fault south of Hollister (Fig. 1) indicate that the fault is not vertical but dips westward. At 12 km depth our data indicate that the contact between the poorly conducting Gabilan granite to the west and the conductive material to the East is about 8 km west of the surface manifestation of the San Andreas fault. If the fault is vertical, rather than dipping westward, these data indicate that a wedge of electrically conductive material lies under the Gabilan granite with conductivity similar to that of the Franciscan sediments to the east.

Our experiments were motivated by the need to evaluate the electrical conductivity in the 2-10 km depth interval where, on the San Andreas fault, most of the destructive earthquake energy is released. Monitoring small, temporal changes in the electrical resistivity in this depth interval holds much promise for earthquake prediction. The design of such a system requires detailed knowledge of both the electrical conductivity and the morphological structure which the present experiments are designed to determine. While most of the crustal strain energy release on the San Andreas fault comes from this depth interval, there is, at present remarkably little, unequivocal geophysical and geological knowledge about it.

Our initial experiments and analysis thereof, may help resolve the long standing dilemma that the epicenters of earthquakes in the Hollister region appear to be systematically displaced up to 5 km west of the surficial trace of the fault[1]. While taking into account the seismic velocity distribution in the area may allow relocating the epicenters eastward, there remains controversey about their true location[1][2][3]. We note that if the hypocenters lie along the sloping contact between the regions of high and low electrical conductivity as indicated by Fig. 2, the epicenters will be 3-6 km west of the fault's surface trace.

Highly conducting material found to the east of the fault is continuous through the fault zone and beneath the Gabilan range, suggesting that the rocks underlying the Gabilans are the same as the sediments to the east. Gravity data[4] indicate a sedimentary wedge extending downward to about 5 km and laterally about 3 km under the Gabilans. Using geologic data, Yeats[5] postulated that the Salinian block was rafted over the Franciscan sediments. The origin of the Salinian block remains in question[6]; the present electrical data impose several important constraints.

Experimental Apparatus and Data Analysis

The experiment was performed using the U.C. Berkeley grounded electric dipole source[7] located at the Law Ranch near Paicines (Fig. 1). The source was operated in a square wave mode with periods of 1 and 10 seconds. The polarization of the source is almost parallel to the fault. All three magnetic

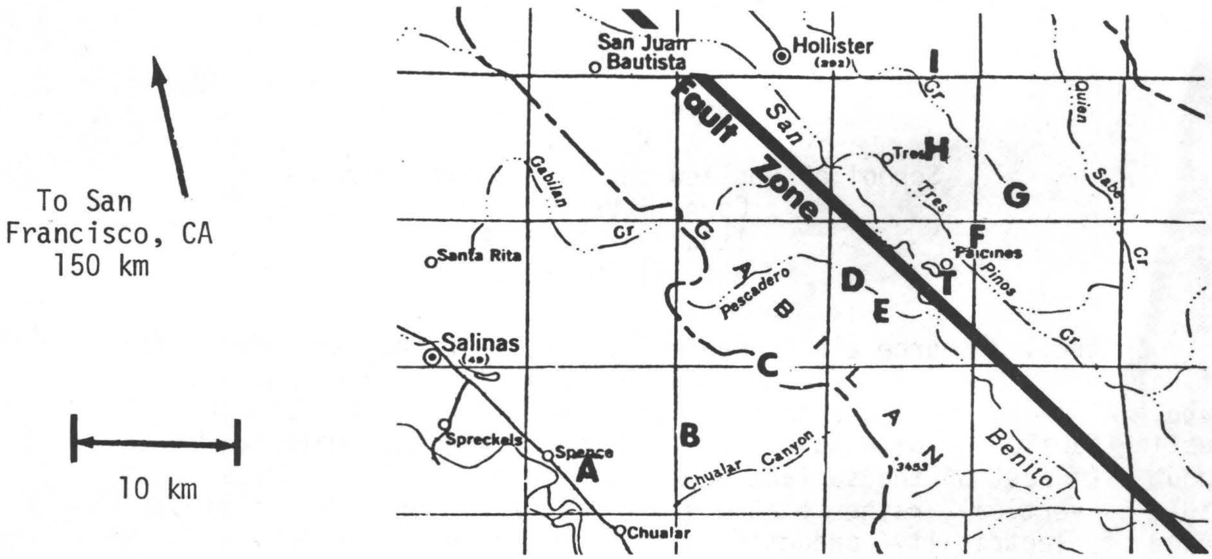


Fig. 1. Experimental stations and their relations to the San Andreas fault.

field components and both electric field components were measured at 9 sites, lettered A-I in Fig. 1.

Magnetic fields were measured using induction coils and electric fields with grounded receiving dipoles (Fig. 3). The analog signals were multiplexed onto a single A/D converter, the output was read and stored by a microprocessor. Each of the five analog signals is sampled 100 times per source cycle. The transmitter and microprocessor are synchronized by two identical 1MHZ crystal oscillators to a few milliseconds accuracy.

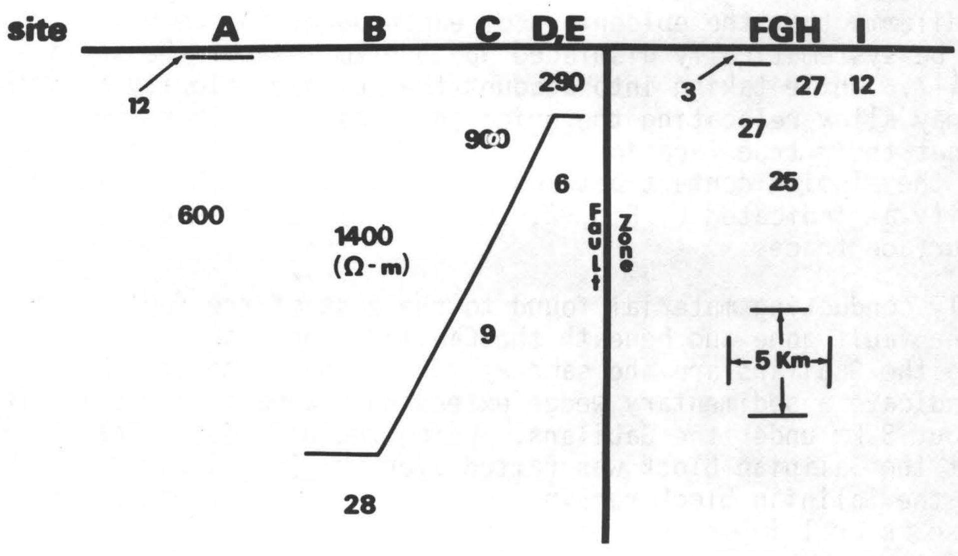


Fig. 2. Electrical resistivity vs. depth across the San Andreas fault south of Hollister, CA derived from controlled source electromagnetic data using approximate, two-layer magnetotelluric methods.

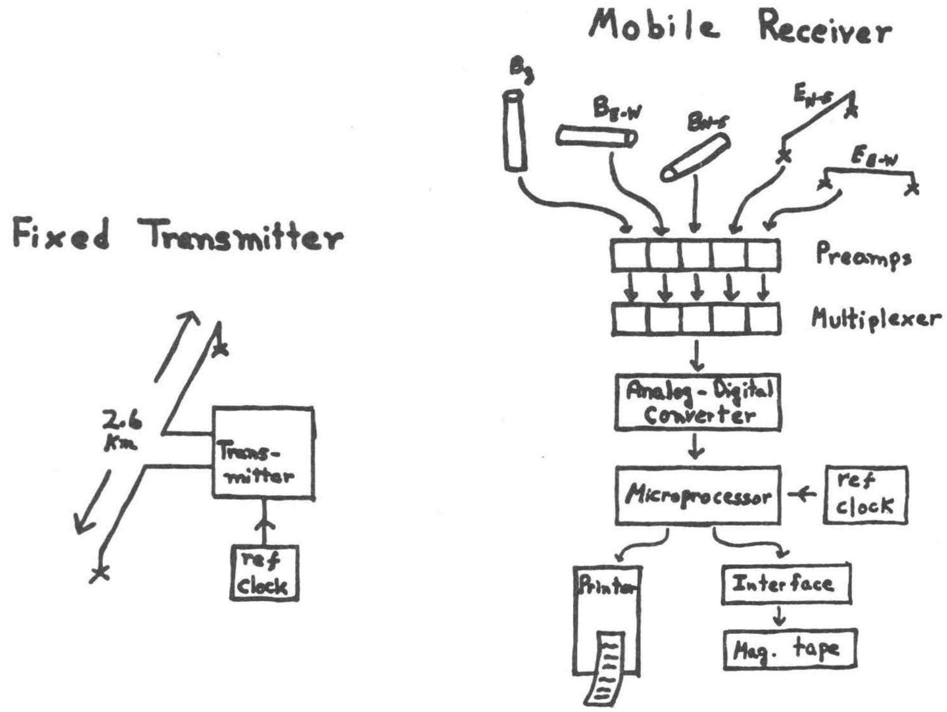


Fig. 3. Block diagram of fixed transmitter at Paicines and of the mobile microprocessor detection and recording apparatus.

Signal averaging is achieved by "stacking", i.e. adding the results of many source cycles in the memory of the microprocessor. After stacking 10-30 minutes, the microprocessor memory is dumped onto a cassette tape recorder and printer. Fourier analysis of the data was done later in the laboratory using a TI 980A minicomputer. The magnitude and phase of the Fourier components are self consistent over two decades in frequency.

The data analysis utilized familiar magnetotelluric principles using plane wave theory and pseudo-sections. The results of analysis are summarized in Table I. The plane wave, apparent resistivity $|E|^2/(\mu_0\omega\ |H|^2)$, was computed from the electric field E, magnetic field excitation H, and frequency $\omega/2\pi$ recorded (MKS units). The models in Fig. 2 were produced by fitting these values of apparent resistivity, ρ_a, to two-layer magnetotelluric sounding curves e.g. Keller and Frischknecht[8]. This analysis will give correct results for data taken at sites where the electromagnetic skin depth $(2\rho_a/(\omega\mu_0))^{\frac{1}{2}}$ is small compared to the distances from the source and from the fault.

The error produced by the finite source to receiver separation was estimated by comparing the two-layer, controlled magnetotelluric source theory[9] to the simple plane wave theory. The derivations due to the two-order of magnitude resistivity change across the San Andreas fault, were considered by noting the computations of Swift[10]

Our experimental data exhibit qualitative deviations, both in magnitude and phase due to the above causes, from the idealized two-layer behavior. In most cases the error of analysis due to the above corrections is not dominant for the data in Table I.

The most serious corrections are expected in applying the two-layer plane wave theory to the data west of the fault since the resistivity model (Fig. 2) indicates a 60 degree interface between the highly resistive Gabilan granite

Freq.Hz	SITE A	B	C	D	E	F	G	H	I
9	44	1870	1280	400	300	3	31	29	13
7	44	1850	1140	330	240	2	23	25	10
5	64	2240	1200	300	220	2	22	25	9
3	100	2430	870	220	160	3	21	27	16
1	140	1390	300	90	66	5	24	29	14
0.9	400	1170	250	80	56	5	24		
0.7	270	780	170	67	44	5	23		
0.5	80	650	130	56	39	6	28		
0.3	100	490	100	49	34	7	26		
0.1	300	390	70	74	48	7	25		

Table I. The magnitude of the apparent resistivity vs. frequency and site. The results from 1 to 9 Hertz were obtained from 1 second excitation of the source, the 0.1 to 0.9 Hertz from 10 second excitation.

and the conductive materials beneath. These corrections are much more difficult to determine.

Data analysis, thus far, has been limited to applying simple, though asymptotically correct methods. The structural complexity of the faulted region coupled with the importance of understanding the fault structure demand doing further analyses and also experiments to conclusively determine the material and geologic structure at the depths where the San Andreas earthquake hypocenters are located. The systematic variation of the data obtained and their coherence with the theory used gives confidence in the qualitative verity of our conclusions.

<u>References</u>

1. Boore, D.M. & Hill, D.P., 1973, Wave Propagation Characteristics in the Vicinity of the San Andreas Fault: in Proc. Conf. Tectonic Problems, San Andreas Fault System, Kovach, R.L., & Nur, A., eds., Stanford Publ. Geol.Sci. 13, 215-224.
2. Healy, J.H., & Peake, L.G., 1975, Seismic Velocity Structure of the San Andreas Fault Near Bear Valley, CA.: Bull. Seism. Soc. Am. 65, 1177-1197.
3. Engdahl., E.R. & Lee, W.H.K., 1976, Relocation of Local Earthquakes by Seismic Ray Tracing: J. of Geophys. Res., V.81, 4400-4406.
4. Pavoni, N., 1973, A Model for the San Andreas Fault Along the NE Side of the Gabilan Range: in Proc. Conf. Tectonic Probs. San Andreas Fault System, Kovach, R.L., & Nur, A., eds., S anford Publ. Geol. Sci. 13, 259-267.
5. Yeats, R.S., 1968, Rifting and Rafting in the Southern California borderland: In Proc. Conf. Geologic Problems San Andreas Fault System, Dickinson, W.R., & Grantz, A., eds., Stanford Publ. Geol. Sci. 11, 307-322.
6. Ross, D.C., 1978, The Salinian Block--A Mesozoic Granite Orphan in the California Coast Ranges: in Howell, D.G. & McDogall, K.A., eds. Mesozoic Paleography of the Western U.S., Soc. Econ. Paleontologists & Mineralogists, Pacific Sec., Pacific Coast Paleography Symposium 2, 509-522.
7. Morrison, H.F., Corwin, F., & Chang, Mark, 1977, High Accuracy Determination of Temporal Variations of Crustal Resistivity: in The Earth Crust, Heacock, J.G., ed., Geophys. Mono., V.20, A.G.U., Washington, D.C., 593-614.
8. Keller, G.V., & Frischknecht, T.C., 1966, Electrical Methods in Geophysical Prospecting, Permagnon Press, N.Y., 219-220.
9. Goldstein, M.A., & Strangway, D.W., 1975, Audio-frequency Magnetotellurics with a Grounded Electric Dipole Source: Geophys. V.40, 669-683.
10. Swift, Charles M., 1971, Theoretical Magnetotelluric and Turam Response from Two-Dimensional Inhomogeneities: Geophys., V.36, 38-52.

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 May-Oct 1979
Contract No. 14-08-0001-16724

Principal Investigators: T.R. Madden and M.N. Toksoz

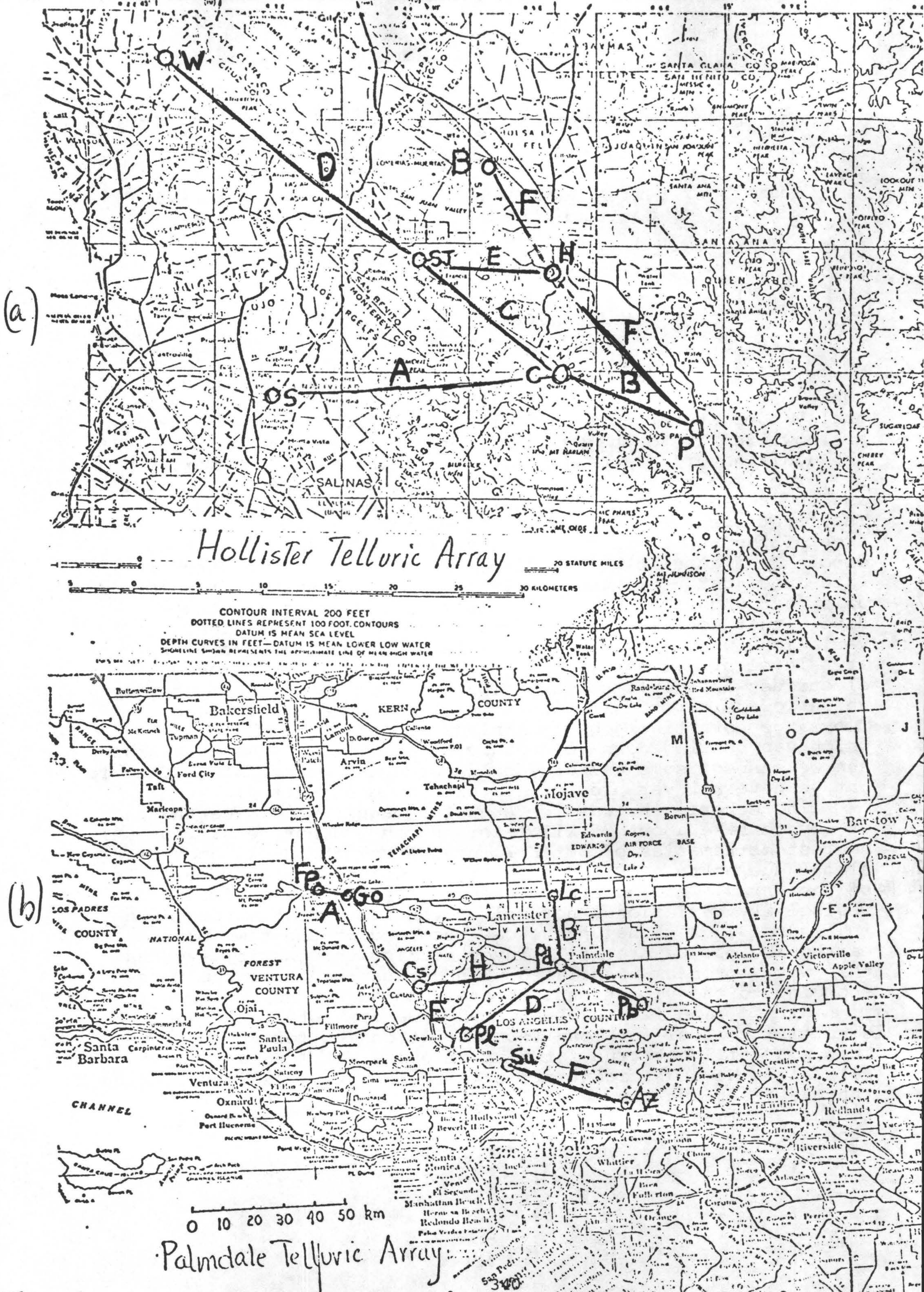
Department of Earth and Planetary Sciences
M.I.T., Cambridge, Mass.

The circuit and electrode changes that are supposed to represent the finalization of the array systems are now virtually complete at both Hollister and Palmdale and both arrays are now tied in to the Cal Tech data retrieval system with the addition of a recording TIM at Hollister this summer.

Two important events took place recently near our arrays and we are searching for significant anomalies in our data. The first event was the recording of radon anomalies near the edge of the San Gabriel Mts not far from the location of our dipole F (figure 1b). The first radon anomalies occurred in late June just as we were installing the new system at Palmdale, and unfortunately a DC offset developed across the F dipole that sent its data offscale. No significant resistivity variations were observed on the rest of the array, however, at a level of 0.1 to 0.2% as seen in figure 2a. The new electrodes are still not functioning completely satisfactorily which lowers our sensitivity to self potential variations. Two large potential jogs took place on July 23 and Aug 16 which can be tied down to Castaic. They look rather unnatural and we suspect some cultural self potential may exist at Castaic, but we have not yet proven this with a local survey.

The other event was the August 6 magnitude 5.3 earthquake at Coyote Lake about 25 kilometers north and northeast from the nearest extremeties of our Hollister array and 31 kilometers almost due north of San Juan Bautista which is about the center of the array. Again here we cannot detect any significant resistivity variations, nor self potential variations as seen in figure 3. A signal pulse was recorded at the time of the earthquake but we are still investigating the possibility that this was a problem associated with one particular circuit responding to the vibrations. We are puzzled by the negative results.

With a finalized system we hope we can obtain the same sensitivity level for long term variations as for short term. This was still not true for most of our digital data from Palmdale. No significant drift in resistivity was found during the past year but the sensitivity level is only about 1% due to the problems associated with changing the system configuration.


(a)
W
D
B
F
ST
E
H
C
F
A
OS
C
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P
Hollister Telluric Array
20 STATUTE MILES
5 0 5 10 15 20 25 30 KILOMETERS
CONTOUR INTERVAL 200 FEET
DOTTED LINES REPRESENT 100 FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES IN FEET—DATUM IS MEAN LOWER LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
SALINAS
(b)
Bakersfield
KERN
COUNTY
Mojave
Barstow
M
O
J
Fp
Po
Go
A
Lc
Lancaster
B
Pd
Palmdale
C
Cs
H
D
E
Pb
Pl
Su
F
Az
Victorville
E
D
VENTURA
COUNTY
LOS PADRES
NATIONAL
FOREST
Santa Barbara
Ventura
Oxnard
0 10 20 30 40 50 km
Palmdale Telluric Array

Fig 1

(a)

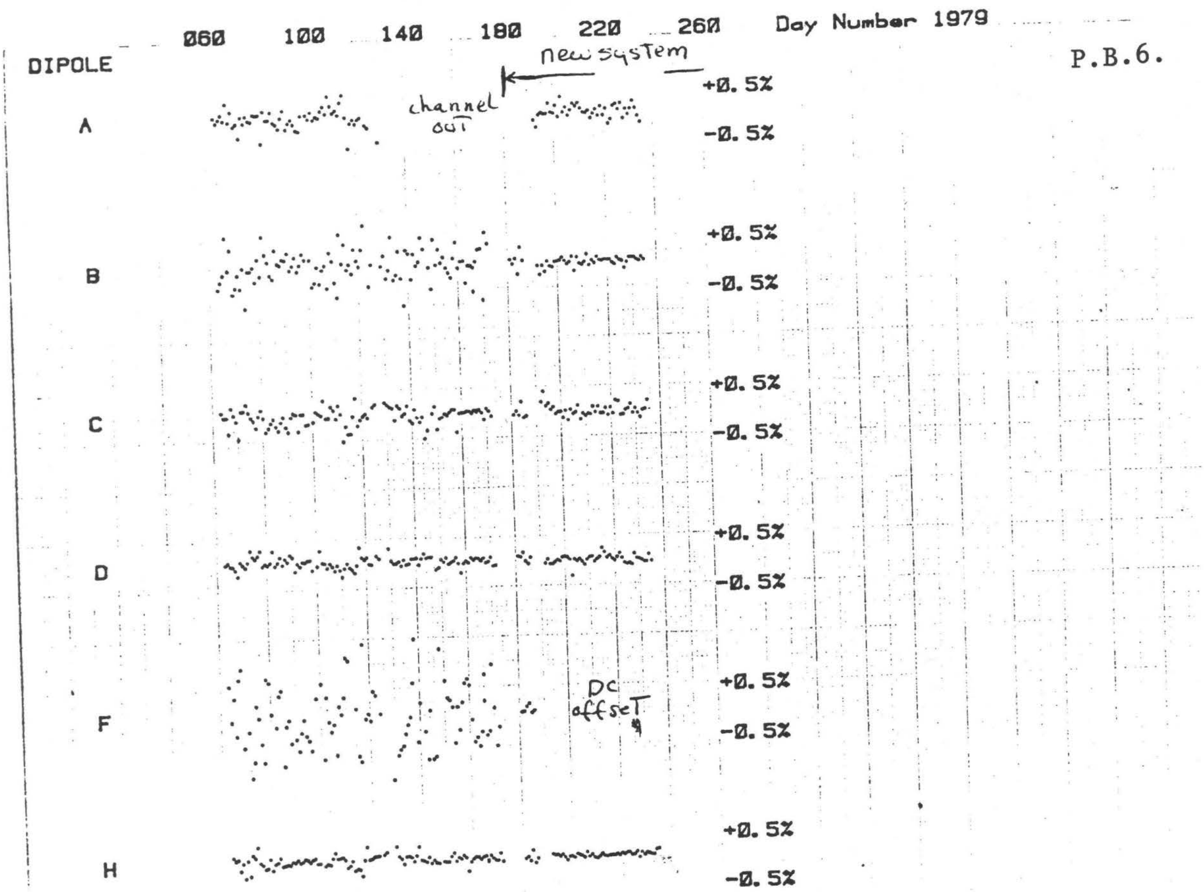

fig 2 RESISTIVITY VARIATIONS PALMDALE ARRAY

(b)

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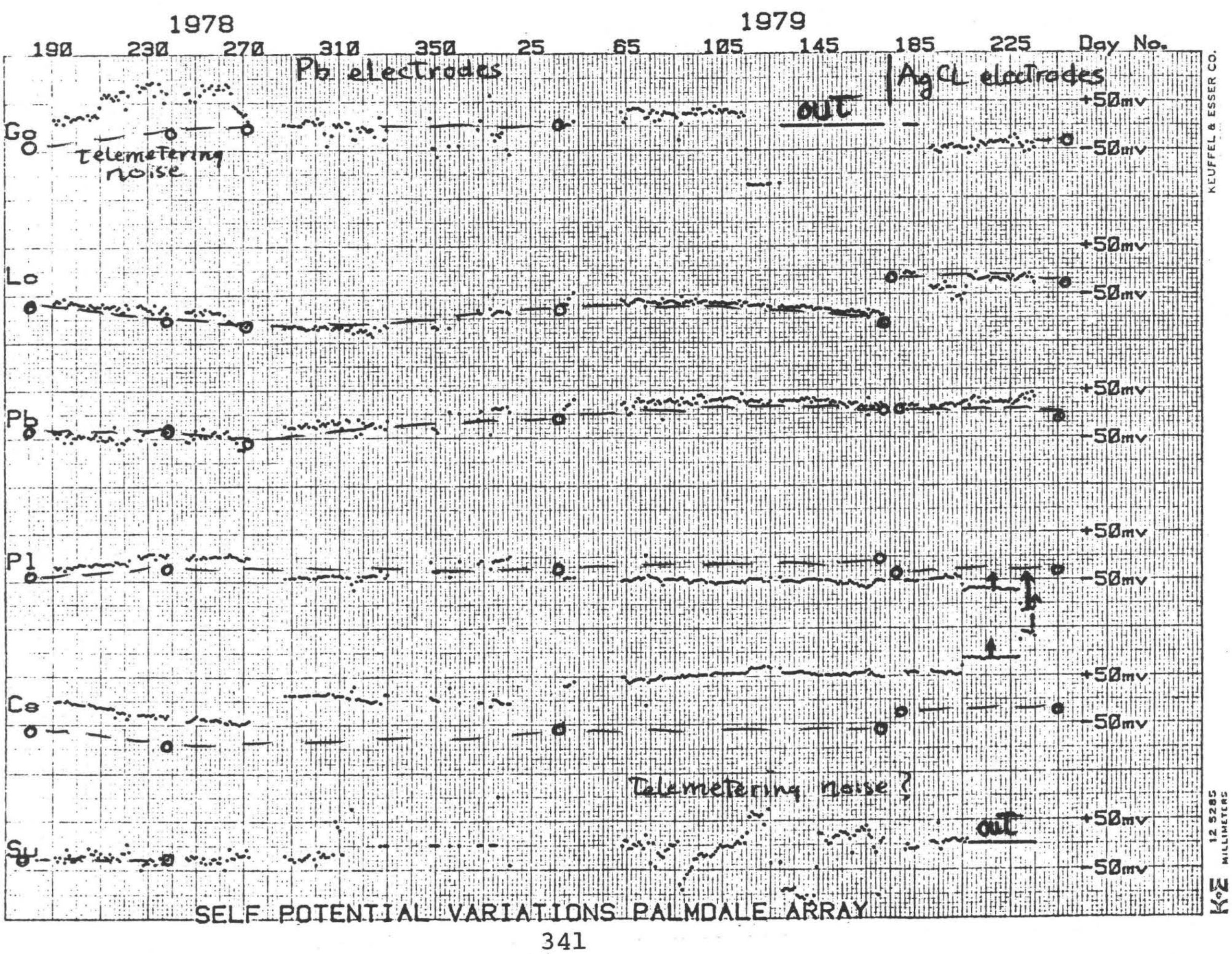
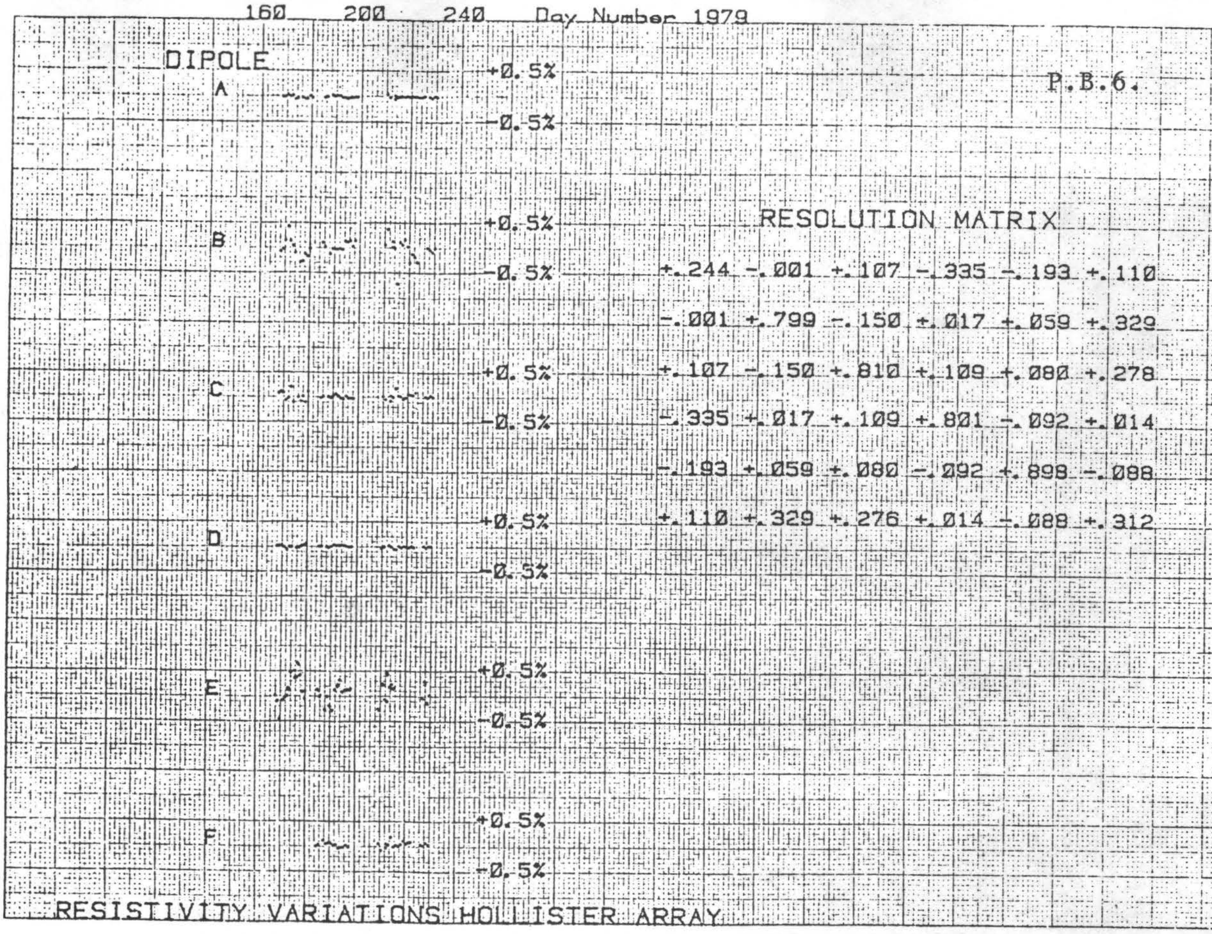


SELF POTENTIAL VARIATIONS PALMDALE ARRAY

(a)

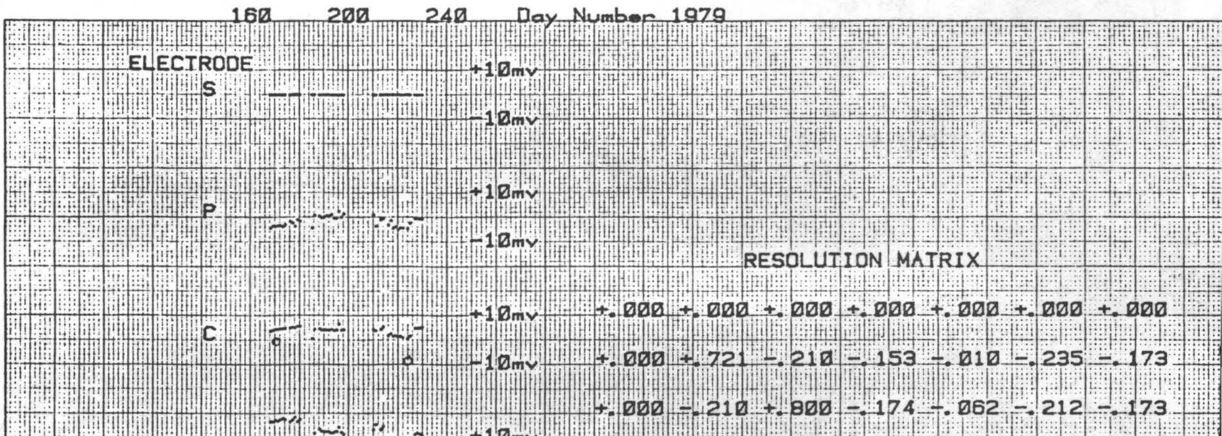


RESOLUTION MATRIX

+.244	-.001	+.107	-.335	-.193	+.110
-.001	+.799	-.150	+.017	+.059	+.329
+.107	-.150	+.810	+.109	+.080	+.278
-.335	+.017	+.109	+.801	-.092	+.014
-.193	+.059	+.080	-.092	+.898	-.088
+.110	+.329	+.276	+.014	-.088	+.312

fig3

(b)



RESOLUTION MATRIX

+.000	+.000	+.000	+.000	+.000	+.000	+.000
+.000	+.721	-.210	-.153	-.010	-.235	-.173
+.000	-.210	+.800	-.174	-.062	-.212	-.173
+.000	-.153	-.174	+.819	-.109	-.175	-.180
+.000	-.010	-.062	-.109	+.857	-.047	-.104
+.000	-.235	-.212	-.175	-.047	+.747	-.173
+.000	-.173	-.173	-.180	-.104	-.173	+.774

Studies of Temporal Variations of Electrical Resistivity and Electrical Fields on the San Andreas Fault

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U.S.G.S. Contract No. -16778

SUMMARY

Technical improvements have been incorporated in the resistivity monitoring equipment to improve the accuracy of measurements. The network has now been operating for over one year under full, remote computer control. Between a prototype pair of transmitter-receiver stations separated by 10 kilometers, the apparent resistivities now have consistent 95% confidence levels of less than 0.5%.

Two natural noise cancellation schemes have been tried, using either remote magnetic or remote electric fields measured at a site approximately 70 km distant from the array. Large local magnetic noise fields at the distant site, and a large electric field dynamic range, have prevented useful implementation of this scheme to date. Preliminary evidence suggests that at worst, several db of cancellation is possible, so the design goal of 0.1% error bars is achievable.

No significant resistivity variations have been detected with the array in the past 6 months. There have been no earthquakes of magnitude greater than 4.0 within the array in this same period

STUDY OF ATMOSPHERIC ELECTRIC PROCESSES AND OF THEIR ASSOCIATION WITH EARTHQUAKES

14-08-0001-17711

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Introduction

Various observations suggest that there may be atmospheric electrical activity associated with earthquakes. If these observations are verified, the detection of such activity could serve as the basis for an earthquake-warning system.

The purpose of this program is to perform a systematic series of measurements of atmospheric electric parameters in an earthquake zone and to establish a data base for testing physical theories and for assessing the possible response of animals to changes in electrical parameters.

Progress

An electric-field monitoring system has been developed and constructed for the continuous measurement of the earth's electric field at the ground. Four such systems are being deployed at selected earthquake zone sites.

Each of these systems consist of a sensitive electric-field sensor and an "intelligent" data acquisition and collection system for efficient recording of electric-field data for subsequent analysis. The data collection system continuously monitors the output of the electric-field sensor and records data on a digital tape cassette at a rate proportional to the rate-of-change of the measured electric field. In this way, the necessity for frequent cassette replacement at remote sites is minimized without compromising system bandwidth during periods of rapid field change.

Future Plans

It is planned that data will be collected over the next year and analyzed to detect and characterize changes in atmospheric electric-field characteristics prior to and during periods of earthquake activity. In addition, it is planned that weather-monitoring instrumentation will be added to each of the four monitoring systems to allow electric-field variations due to local weather changes to be recognized and correctly interpreted during data analyses.

RADON AS AN EARTHQUAKE PRECURSOR IN ICELAND

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Lamont-Doherty Geological Observatory
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Sponsored by the
U.S. Geological Survey
Grant No. 14-08-0001-17726

JUNE 1979

REPORT SUMMARY

We report radon data collected from 1 November 1978 to 30 April 1979 from geothermal wells in Iceland. Discrete radon samples are being collected weekly from eight stations in the Southern Iceland Seismic Zone (SISZ) and two stations in the Northern Iceland-Tjörnes Fracture Zone (TFZ) to determine the potential for earthquake prediction. A radon anomaly was observed in the SISZ at the sampling station Flúdir prior to an earthquake (M=4.2). This event occurred 19 November 1978 near the sampling station Kaldarholt. No radon anomalies related to this earthquake can be identified at any other stations. Samples are being collected less frequently in the Krafla-Námafjall high temperature geothermal fields in Northern Iceland to determine if radon can be a useful parameter to predict the periodic spreading episodes associated with the Krafla Caldera. Descriptions of the sampling localities and radon data collected at each locality are presented.

Methods for sampling the two phase geothermal fluids from both low temperature (T_W<100°C) and high temperature (T_W>100°C) geothermal areas are discussed.

Future plans are outlined which include improving the sampling network in the SISZ and the routine measurement of chloride and conductivity on each radon sample in an effort to understand the possible mechanisms involved in radon anomalies. We have also started development of a continuous radon monitor to aid in determining the shape and duration of long- and short-term radon anomalies and the relationship of these anomalies to other physical parameters at the well.

RADON AS AN EARTHQUAKE PRECURSOR IN ICELAND

Contract # 14-08-0001-17726

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Palisades, N.Y. 10964

Report Summary

We report radon data collected from 1 May 1979 to October 1979 from geothermal wells in Iceland. Discrete radon samples are being collected weekly from seven stations in the Southern Iceland Seismic Zone (SISZ) and two stations in the Northern Iceland - Tjörnes Fracture Zone (TFZ) to determine the potential for earthquake prediction.*

During this time period two microearthquakes occurred close to our radon sampling stations. The first occurred on August 12 (M=2.7) about 5 to 15 km west of Selfoss. The second occurred on September 5 (M=2.7) about 12 to 16 km south of Flúdir. No radon anomalies related to this earthquake activity can be identified at any of our stations.

The floor of the Knafla caldera subsided during May 13 to May 18. A coepisodic doubling of radon content was observed in gas samples collected from a local hot spring at Leirhnjúkur. This increase in radon decayed rapidly down to base level in 20 days. The next subsidence event at Knafla is expected this month. In late August and early September, 23 different hot springs, steam vents and fumaroles within the Knafla caldera were sampled for radon analysis. Latest reports from Knafla indicate increased fumarolic activity in the southeastern part of the caldera but no earthquake activity has commenced yet.

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*We also keep track of wellhead temperature and chloride content of the water to enable us to constrain the possible mechanism involved in radon anomalies.

Assessment of the $^{234}U/^{238}U$ Activity Ratio as a Possible Earthquake Precursor

14-08-001-17744

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Investigations

This report describes work done during the past six months as part of a study to assess the utility of the U-234/U-238 activity ratio as a possible earthquake precursor. Uranium concentrations and isotope ratios have been measured in water from wells and springs at 24 Southern California sites located in six tectonic areas:

1. San Andreas Fault (Palmdale Area)
2. San Andreas Fault (San Bernardino Area)
3. Mission Creek-Banning Fault
4. San Andreas Fault (Imperial Valley Area)
5. San Jacinto Fault
6. Elsinore Fault

A monitoring network has been set up comprising 14 sites along the San Andreas, San Jacinto, and Elsinore fault systems in the region between San Bernardino and the Mexican border. Along this primary monitoring network activity ratios, U-234/U-238, vary from 0.88 at Agua Caliente Springs (ACAL-1S) on the Elsinore Fault to 4.2 at Niland Slabs (NILA-2W) just east of the Salton Sea. Uranium concentrations vary from 0.002 ppb at Indian Canyon Springs (INCA-1P) on the San Jacinto Fault to 4.6 ppb at Frink Spring (FRNK-1P) on the San Andreas Fault in the Imperial Valley.

At these 14 sites uranium concentrations are determined on a monthly or bimonthly basis. Within the experimental uncertainty as determined by counting statistics, the U-234/U-238 activity ratios have remained constant from month to month. The absolute uranium concentrations vary much more than do the isotope ratios, but there is as yet no discernable pattern to the observed concentration variations.

During the report period there were four earthquakes in the study area of magnitude greater than 4.0. Of these only one, the event of 13 June 1979 - magnitude 4.1, epicenter just south of the Salton Sea - was at all closely associated with one of the uranium sampling sites. This earthquake had its epicenter about 24 km SW of Niland Slab well (NILA-2W). NILA-2W, which exhibits the highest activity ratio of any site being monitored, has to date shown no unusual changes in uranium content.

Results

Table 1 summarizes the U-234/U-238 activity ratios for the 14 sites which comprise the primary sampling network. The locations of these sites are given in Figure 1. Measurements are separated by at least one month. In all cases the relative standard deviation of the set of measurements is not significantly larger than would be expected from the analytical uncertainty. The relative standard deviation gives an indication of the magnitude of the earthquake precursor signal which could be detected. Although no absolute regional correlations exist, there is a tendency for Imperial Valley sites to have the highest activity ratios and for sites along the Elsinore Fault to have low ratios.

TABLE 1 : TEMPORAL VARIATION OF $^{234}U/^{238}U$ ACTIVITY RATIOS

Site Code	Number of Measurements	Mean $^{234}U/^{238}U$	% Standard Deviation
AROW-1P	3	1.1 ± 0.1	9%
DSRT-1W	8	1.00 ± 0.03	3%
PALM-1P	2	1.2 ± 0.1	8%
HMIN-2W	5	1.59 ± 0.06	4%
BASH-1W	7	1.87 ± 0.06	3%
FRNK-1P	4	1.99 ± 0.02	1%
NILA-2W	4	3.4 ± 0.6	18%
EDEN-1P	4	1.31 ± 0.08	6%
SOBO-1S	7	1.04 ± 0.03	3%
INCA-1P	4	1.3 ± 0.4	31%
ROBI-1W	10	1.17 ± 0.02	2%
ELSI-1W	6	1.14 ± 0.05	4%
WARN-1P	4	1.1 ± 0.2	18%
ACAL-1S	5	0.88 ± 0.01	1%

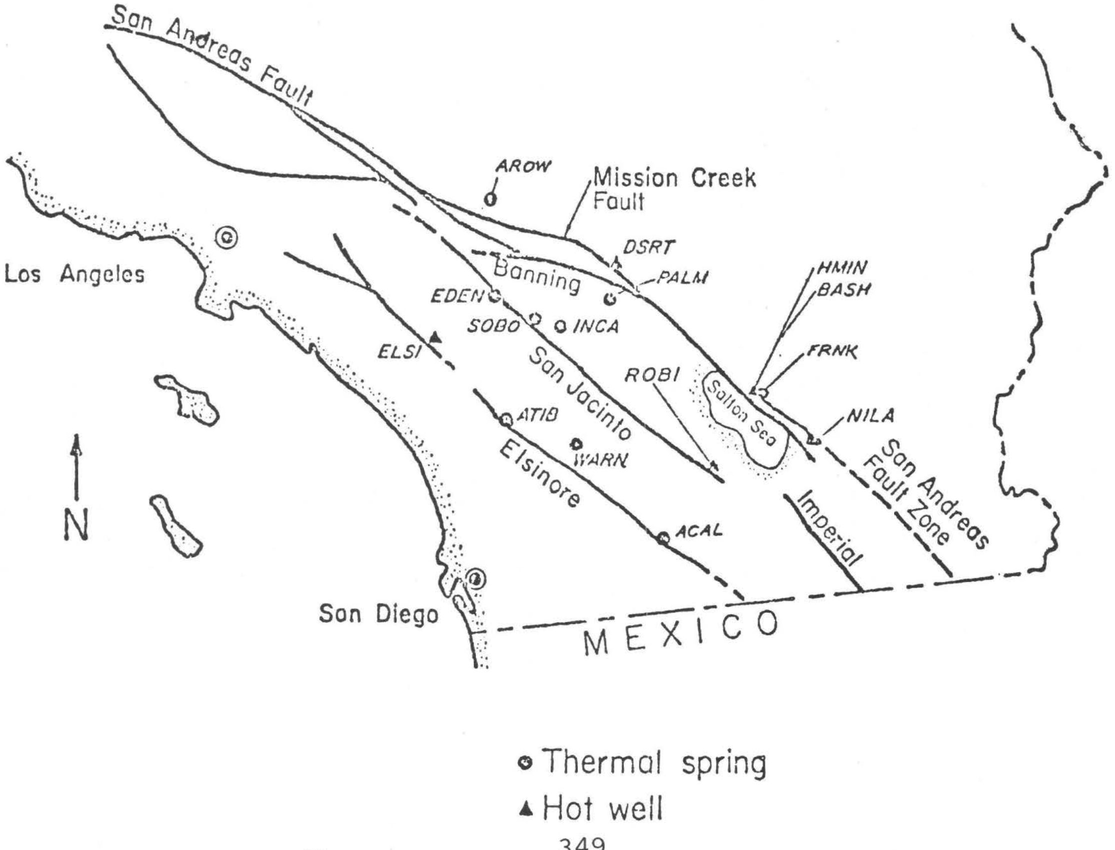

Figure 1. Location map for the Southern Network

RADON AND WATER-WELLS MONITORING

9960-01485

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Investigations

1. Radon content of subsurface soil gas was continuously monitored by the Track Etch method in capped shallow holes at about 80 sites along several active faults between Santa Rosa and Cholame in central California, 35 sites in southern California (in cooperation with USC, UCSD, and UCSB), 10 sites in Hawaii (with HVO) and 10 sites in Fairbanks area, Alaska (with UA).

2. Radon content of ground water was continuously monitored at two artesian wells in San Juan Bautista, California (in cooperation with University of Tokyo) and near Banning, California (with USC and University of Tokyo).

3. Water level was continuously recorded and several water quality parameters (temperature, salinity, conductivity, pH) were periodically measured at 5 wells in central California.

4. Water quality and flow rate were periodically measured at two springs near Calaveras fault in San Jose, California.

5. Water samples were collected from the above-mentioned wells and springs and were sent to two USGS groups (I Barnes and J R O'Neill) for chemical and isotopes analyses.

6. A weather station was maintained at Stone Canyon, California. Weather data were collected from a few other local weather stations.

7. Soil-gas samples were periodically collected from eight radon-monitoring sites and were sent to G. M. Reimer of USGS for helium-content measurement.

Results

Radon and groundwater data recorded in central California were examined to see whether they showed any premonitory changes for a magnitude 5.7 earthquake that occurred on August 6, 1979 near Coyote Lake on the Hayward-Calaveras fault. Preliminary results indicate that, while no significant changes were recorded at two radon stations which are closest to the earthquake epicenter, the radon content of subsurface soil gas showed a broad-scale increase along the Hayward-Calaveras fault between San Jose and Hollister. The radon content began to increase at about the beginning of 1979 and reached a peak of twice the long-term average level in June, 1979, about one month before the quake. Significant radon increases were also recorded along the Hayward fault and its northern extension between San Jose and Santa Rosa, but not elsewhere within the monitored area. This episode of increased radon emanation is longer in duration, larger in spatial extent but comparable in amplitude, when compared with several earlier episodes which were previously found to be correlated with smaller earthquakes of magnitude 4.0 to 4.3.

Groundwater showed 4-6°C changes in temperature at two springs in San Jose and a water well in San Juan Bautista during several months before the quake. One of the springs for which the flow rate was measured, showed significant changes in flow rate also. More data are needed to test whether these changes are premonitory or seasonal in nature.

Reports

King, C.-Y., and L. E. Slater, 1978, A comparison of soil-gas radon and crustal strain data (abs)., Earthquake Notes, 49, no. 4, p. 44.

King, C.-Y., in press, Soil-gas radon-concentration data recorded at the time of the Coyote Lake earthquakes of Aug. 6, 1979, EOS, Trans. Am. Geophys. Union.

King, C.-Y., in press, Geochemical measurements pertinent to earthquake prediction (forward): J. Geophys. Res.

Radon Analysis for Southern California Earthquake Prediction

14-08-0001-16772

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G. F. Birchard

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Investigations

The relaionship between soil radon concentration changes and earthquakes was investigated. The effect of non-seismic phenomena such as rainfall and temperature changes on radon measurements was analyzed. The shallow soil sites for radon measurement were located along the San Jacinto Fault zone between Anza and Borrego Springs, California. Plastic Track Etch® radon detectors were used.

Results

A M4.4 earthquake located 15km distant from the nearest site occurred on 5 June 1978. A peak in radon concentration was observed in the last three weeks of May and first two weeks of June. This peak was much above background and was not produced by meterological effects. On 12 February 1979 a M4.2 earthquake took place 5km from the nearest site. Fourteen sites were within 12km of the earthquake which was located in the middle of the instrument array. Prior to the earthquake radon concentrations decreased in the quadrant west of the epicenter while they increased to the south. After the earthquake the pattern reversed. A first motion study showed that the earthquake was right lateral strike slip; therefore, radon concentration increases occurred during compression and decreases during dilation. These results are supported by earlier measurements taken around the time of the 11 August 1976 M4.3 earthquake which had an epicenter located just 4km from the two northernmost sites. A radon peak measured for several weeks prior to the earthquake had an inverse relationship between the peak intensity at a site and the distance of the site from the epicenter. All sites were in pre-seismic compression. Extremely low radon concentrations were observed for three months following this strike-slip earthquake while the sites were in the quadrant of dilation. Radon increases occur when the upward velocity of soil gas increases since a sharp radon gradient exists in the top few meters of soil. Gas outflow may occur in regions of compression and inflow in areas of dilation thus producing the observed radon concetration changes.

We conclude that soil radon measurement is an effective technique for earthquake prediction research. We postulate that the soil radon concentration changes before and after earthquakes are responses to volumetric strain changes in the column of soil and rock beneath the site.

Publications

Birchard, G.F., 1978. Soil radon monitoring for earthquake research - A study of radon concentrations using alpha-particle sensitive films in shallow soil holes along the San Jacinto Fault in Southern California (Ph.D. dissertation): University of California, Los Angeles.

Birchard, G.F. and W.F. Libby, 1979, Soil radon changes preceeding and following four M4.2 - M4.7 earthquakes on the San Jacinto Fault in Southern California: preprint, submitted to Journal of Geophysical Research.

COMPARISON OF RADON MONITORING TECHNIQUES THE EFFECTS OF THERMOELASTIC STRAINS ON SUBSURFACE RADON AND THE DEVELOPMENT OF A COMPUTER OPERATED RADON MONITORING NETWORK FOR EARTHQUAKE PREDICTION

14-08-0001-17734

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Investigations:

1. Side-by-side comparison of the Caltech automated radon-thoron monitor with a Wakita type radon monitor and with the LBL gamma-ray radon daughter monitor at San Juan Bautista began in mid-January 1979. Data from the Caltech instrument and from the LBL monitor are transmitted over the call-up telemetry system to Kellogg Laboratory for analysis.

2. New monitoring sites have been established at Big Dalton Canyon Dam and Lytle Creek ranger station in southern California. Both of these units are located over static boreholes in rock.

3. Data collection from the prototype monitor at Kresge was terminated in April, and this monitor was replaced with the production model, fully automated unit.

4. The central computer system at Kellogg lab was completed, and software developed for the transfer of data from the field units to the central computer. Software for fully automated data analysis and presentation is under development. Until this is complete a semi-automatic analysis routine is in use.

Results:

1. Preliminary comparison of data from the LBL and Caltech monitors at San Juan Bautista has shown that these two instruments track well. The Caltech instrument is more sensitive to changes in radon level probably owing to the direct subtraction of thoron and background.

2. The new monitors at Dalton and at Kresge exhibit linear, short-term temperature dependences similar to that of the original Kresge prototype. The data from Lytle Creek appear to show considerable variation with changes in hydrology, and this masked the temperature dependence, if any, during the winter and spring. Further attempts to determine the short-term temperature dependence at Lytle Creek will be made during the dry months.

3. A possible precursor of approximately 45 days duration was observed from the Kresge monitor prior to the 1 January 1979 Malibu earthquake. This is shown in Fig. 1, where the spike like character of the signal is apparent in the 24-hour running average of the data. This event took place approximately 54 km to the west of the monitor.

4. A new spike type anomaly at Kresge, which began on 21 June 1979 is being monitored at this time.

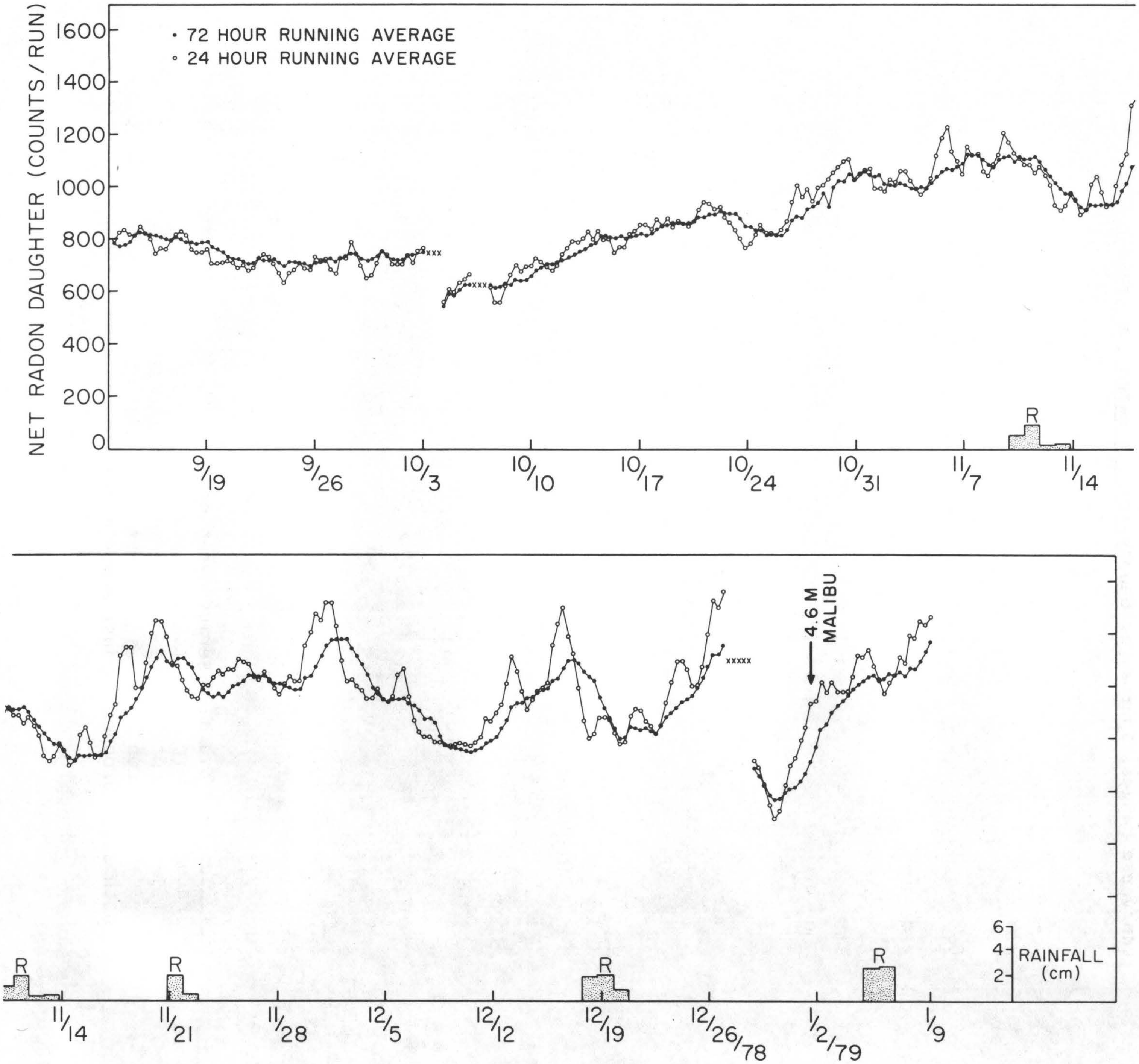
Reports:

Shapiro, Mark H. 1979, Computer Controlled Collection of Radon Data for Earthquake Prediction Research. Invited paper, American Physical Society

Meeting, Washington, D.C. April 24, 1979.

Shapiro, M. H., J. D. Melvin, T. A. Tombrello, and J. H. Whitcomb, Automated Radon Monitoring at a Hard-Rock Site in the Southern California Transverse Ranges, Journal of Geophysical Research, in press.

TEMPERATURE CORRECTED RADON DATA 9/78 - 1/79



P.B.7.

GROUND WATER RADON CONTENT AS AN EARTHQUAKE PRECURSOR P.B.7.

Contract No. 14-08-0001-15875

UNIVERSITY OF SOUTHERN CALIFORNIA

Ta-liang Teng, Principal Investigator
(213) 741-6124

April 1, 1979 to September 30, 1979

Summary

Ground water radon measurements within the area of the Southern California Uplift began in 1974. In the fall of 1976, the network of field sites was substantially increased. Since that time, ground water radon monitoring, either on a weekly or monthly basis, has been carried out at the thirteen sites shown in figure 1 (plus one site in Owens Valley).

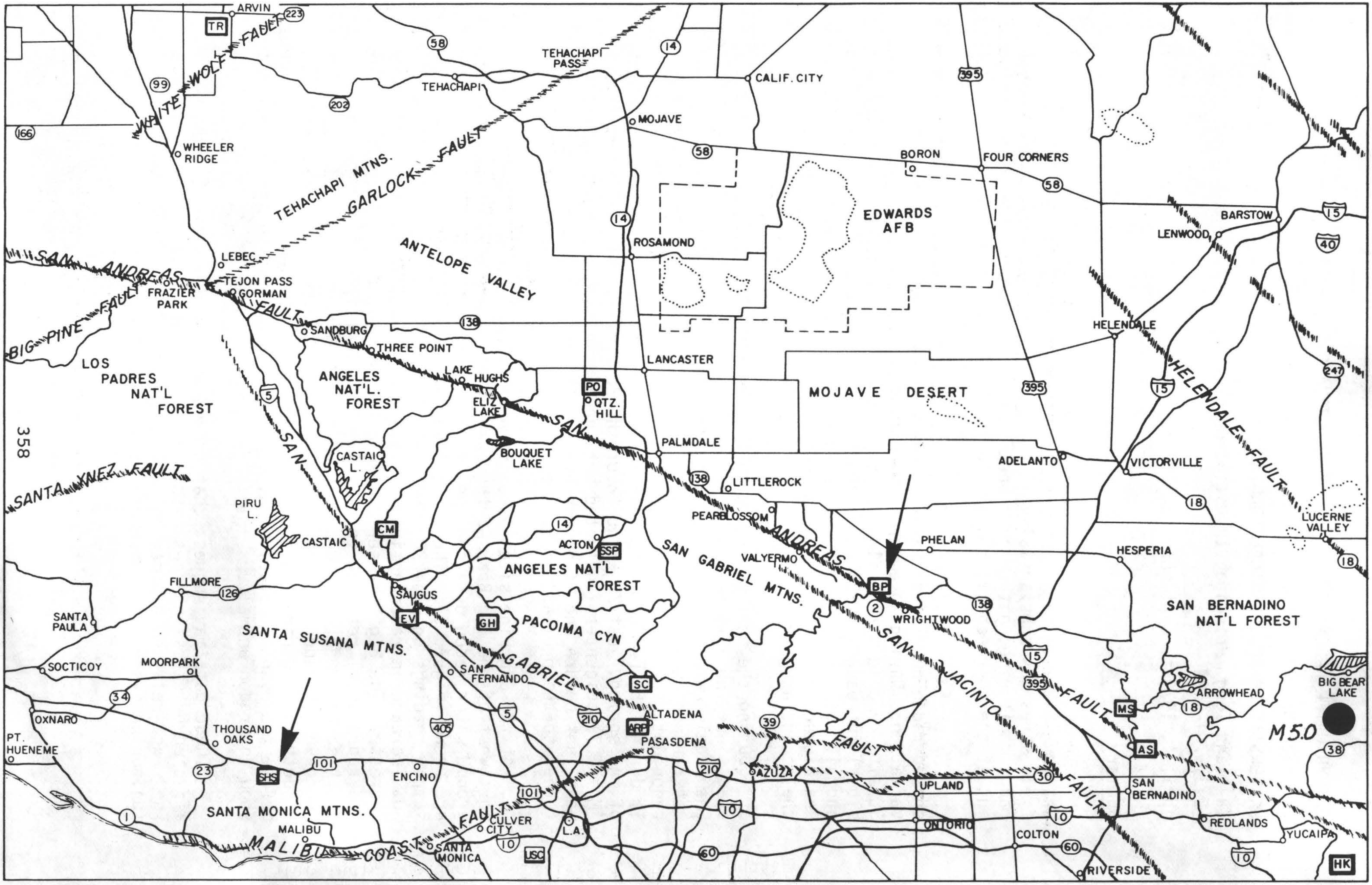
Prior to the fall of 1978, only station SC (30 km north of Pasadena) showed radon anomalies that could not be accounted for by seasonal variation. During November 1976 and April 1977, radon content at the SC site (a cold spring flowing directly out of a fissure in a granite block) increased to 135% and 170% above normal, respectively. The first anomaly appeared before an earthquake swarm that occurred nearby in the Pearblossom area. There was no seismicity in the area at the time of the second anomaly.

During the past year, two earthquakes (the largest events in the area since the 1971 San Fernando earthquake) have occurred in the greater Los Angeles area that were (if indeed related) preceded by major ground water radon anomalies at nearby monitoring sites. Figure 2 shows the radon data for the SHS site (a hot spring indicated by an arrow in figure 1) during the period of October 1976 - October 1979. The radon content of the spring, just 20 km north of the January 1, 1979 Malibu earthquake ($M = 4.7$) epicenter fluctuated between 1/2 and 3 times the three-year mean just before and after the event. The radon level has not yet returned to the pre-earthquake mean.

At the Big Pine site (also shown in figure 1 by an arrow), 50 km northwest of the Big Bear earthquake series (largest event of $M \sim 5.0$), ground water radon data for the period of October 1976 - October 1979, are shown (figure 3). The radon level was remarkably stable until the sample readings on June 20, and June 27, 1979. The first date shows a 30% increase in radon activity, while the second date shows a 400% increase. The Big Bear series began on June 28, 1979. After the event, the radon level returned to normal. In addition, sites at MS and AS (both sampled monthly), nearer the epicentral region, showed $\sim$ 100% increases in radon level eight weeks before the events. The radon level at both sites dropped to just above normal in the sample taken four weeks before the events. Station HK, a continuous monitoring system, did not show any radon anomaly.

These data may suggest that ground water radon content might be affected by stress changes before moderate-sized earthquakes or larger. The exact relationship may be made clearer by the expanded use of continuous monitoring systems now underway across our network.

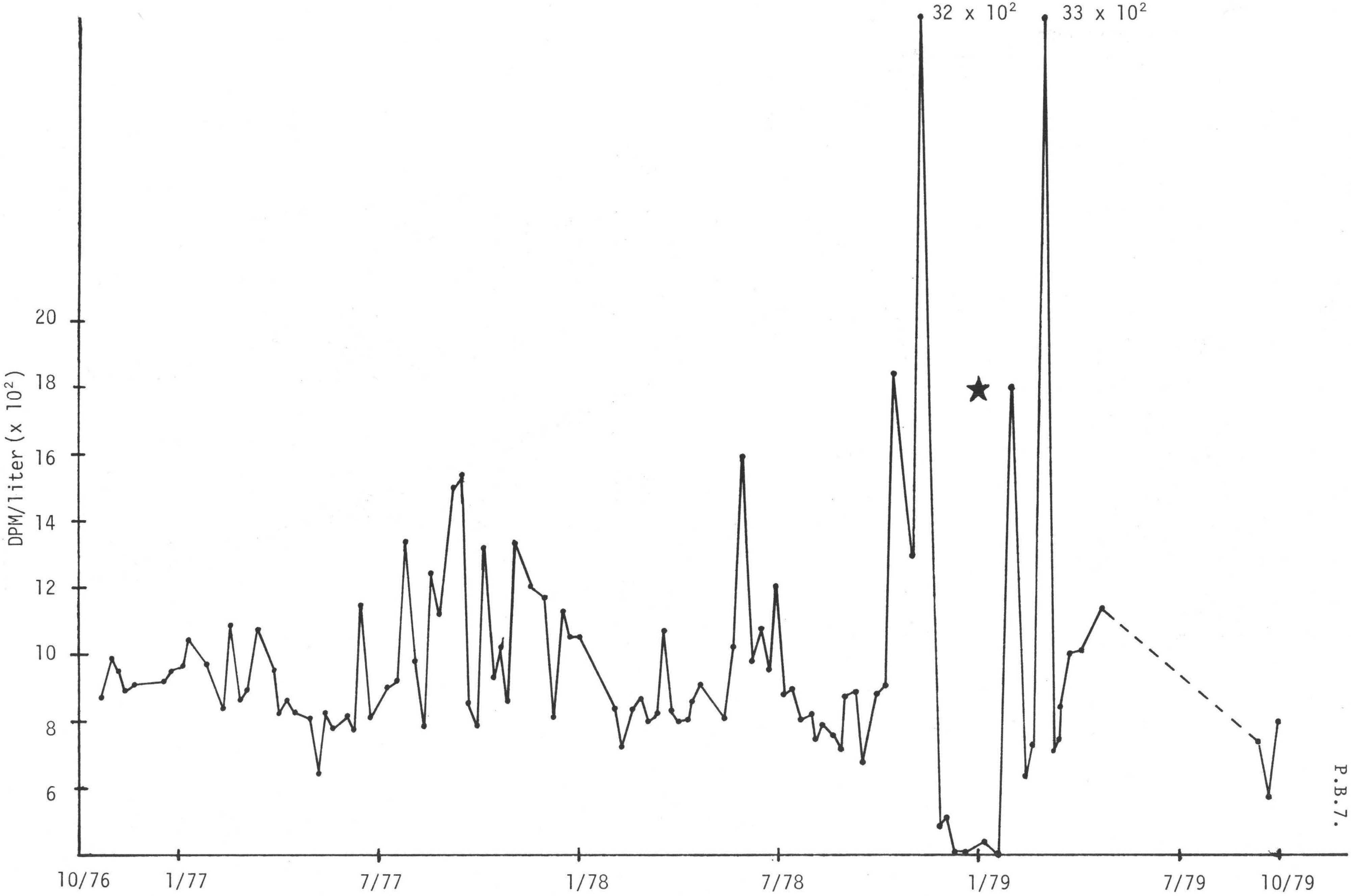
Figure 1



M4.7

XX GROUNDWATER RADON SAMPLING STATION

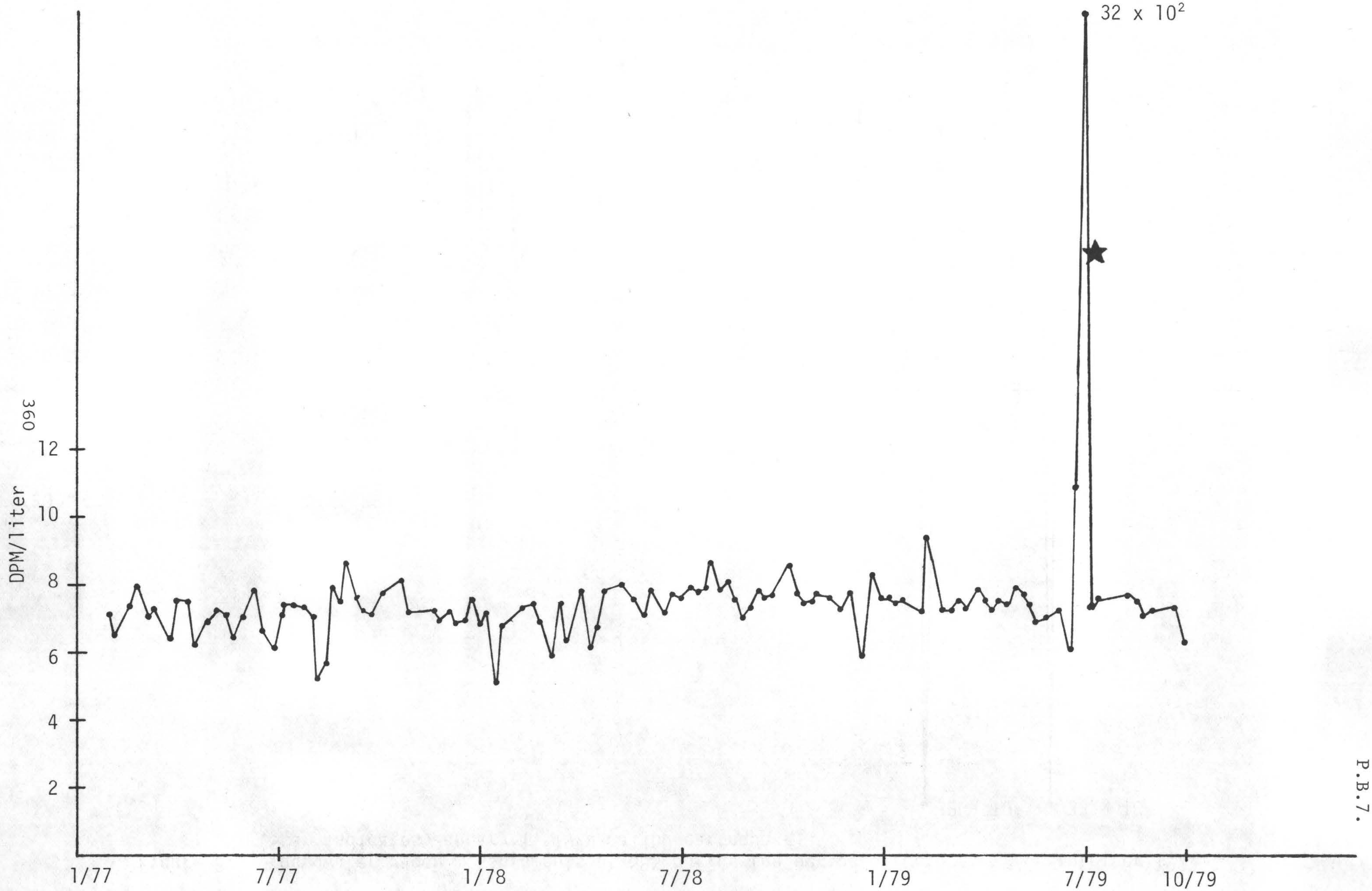
Figure 2. Groundwater radon measurements at SHS during the period of October 1976-September 1979. (Star indicates January 1, 1979 Malibu earthquake)



359

P.B.7.

Figure 3. Groundwater radon measurements at BP during the period of January 1977-September 1979. (Star indicates June 28, 1979 Big Bear earthquakes)



WATER LEVEL MONITORING ALONG SAN ANDREAS AND SAN JACINTO FAULTS, SOUTHERN CALIFORNIA, DURING FISCAL YEAR 1979

Contract No. 14-08-0001-17680

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Investigations

Beginning in October 1976, a program of water-level monitoring of abandoned water wells was initiated in the Palmdale area with the purpose of identifying possible water-level changes premonitory to a major earthquake on the San Andreas fault. In October 1977, the program was extended southeastward along the rift zone to the Valyermo area. In November 1977, the monitoring of water wells along the San Jacinto fault was initiated with the expectation of experiencing a moderate size earthquake while monitoring was in progress. Currently, about 40 wells are being monitored. Eight wells are monitored continuously with Stevens Type F recorders; a ninth well is monitored by a recorder developed during this program. The latter can be inserted entirely into the well casing, making it essentially vandal-proof.

The remaining wells are probed weekly, or is some cases semi-weekly, by volunteers. We are endeavoring to improve the volunteer program by increasing the frequency of measurements and simplifying the procedure to minimize measurement errors.

Weekly water-level data are displayed on computer-generated hydrographs for each well. Rainfall and earthquakes are plotted on the graphs for direct comparison with water levels. The hydrographs are updated and reviewed weekly. Weekly hydrographs are also prepared from recorder charts on wells maintained by W. R. Moyle, Jr., of the U.S. Geological Survey, Water Resources Division Office, Laguna Niguel, California.

A Remote Observatory Support System (TIMS) constructed by the Caltech Seismological Laboratory has been installed at a well in Juniper Hills to telemeter water-level data to Caltech. A second installation is currently planned for Anza.

Results

Several earthquakes of magnitude 3.0 or above occurred within 25 miles of our observation wells along the San Jacinto fault zone. One well in San Jacinto Valley showed an anomalous rise of about 1.5 feet during late July and early August, three to four weeks prior to the M4.1 earthquake on

22 August 1979, which was centrally located within the San Jacinto fault zone. No rainfall occurred that would explain this rise, which is supported by two measurements. Fluctuations in the hydrograph for this well also occurred prior to two M3.0 earthquakes earlier in the year, but these were during the rainy season and could be accounted for by rainfall. Another well in San Jacinto Valley showed an abrupt drop of about 4.5 feet and recovery beginning one to two weeks prior to the M4.1 earthquake. A third well in San Jacinto Valley showed no anomaly during the same period.

The epicenter of the 22 August 1979 earthquake was roughly an equivalent distance between our wells in Anza and those in San Jacinto Valley. Well 7S/3E-23B1 in Anza showed large unexplained fluctuations in water level during 1979 (Fig. 1). In May, it rose over 4 feet, then abruptly dropped 8 feet in June, and then rose sharply 16 feet in July. Since mid-July, the rise has leveled off. A relation between this behavior and rainfall patterns is not apparent. Two other wells in Anza, both of which were monitored throughout 1979 with Stevens recorders, showed no large fluctuations during the same period. It should be noted that -23B1 is deeper (185 feet) than the other two wells (83 and 94 feet). The anomalous drop in water level of -23B1 occurred in June 1979, about two months before the anomalies in the two San Jacinto wells occurred.

In summary, two of three wells being monitored in San Jacinto Valley and one of three wells in Anza showed abnormal behavior prior to the M4.1 earthquake of 22 August 1979. The anomalies occurred at different times, which varied from nearly three months to one-two weeks prior to the earthquake. Anomalies in three of six wells, occurring at different times, do not constitute a particularly strong case for precursor phenomena.

A well in the Borrego Springs area showed four spikes which may be precursors to earthquakes which occurred within 25 miles. The significance of these spikes is questionable because several earthquakes occurred without similar spikes. The largest earthquake that could be related to an anomalous rise in the water level of this well had a magnitude of 4.2 and occurred on 12 February 1979, approximately midway between our observation wells in Anza and Borrego Valley. No change in water level precursory to this earthquake was observed in the other two wells in Borrego Valley nor in three of the four wells being monitored in Anza. However, an apparently anomalous 1.2-foot drop in water level in well 7S/3E-23B1 in Anza (Fig. 1) occurred in mid-January 1979 about one month before the earthquake.

Two wells showed particularly anomalous behavior during the reporting period, 11S/8E-33P1 in Ocotillo Wells (Fig. 2) and 7S/3E-23B1 in Anza (Fig. 1). The possible relation between these anomalies and the strong earthquake in Imperial Valley on 15 October 1979 should be considered. Preliminary reports place the earthquake near the U.S.-Mexico border on the Imperial fault, which is generally considered to be a strand in the San Jacinto fault zone. A preliminary estimate of the magnitude is MS=6.8 (K. C. McNally, Caltech, 22 October 1979). Well 11S/8E-33P1 in Ocotillo Wells is about 60 miles (100 km) northwest of the epicenter. The anomalously low measurement (Fig. 2) in mid-July, three months prior to the earthquake, was followed by an abrupt rise. Recent measurements subsequent to those on the hydrograph (Fig. 2) indicate that the water levels in this well have returned to levels similar to those before the anomalous drop in mid-July.

In contrast, neither of the other two wells being monitored in the Ocotillo Wells area showed such an anomaly. However, water levels in two other wells in Ocotillo Wells showed a rise in mid-July of about 0.06 foot and about 0.03 foot at the same time. These rises would not be considered anomalous by themselves; however, it is perhaps significant that they occurred at the same time as the unusual drop and immediate rise in water level in well 11S/8E-33P1. Water levels in well 11S/8E-33P1 could be expected to be more responsive to strain than those in the other two wells in the Ocotillo Wells area because of greater depth. Well 11S/8E-33P1 has a depth of 374 feet, which is at least 174 feet deeper than the other two wells.

An alternate hypothesis for the abrupt rise in water level in well 11S/8E-33P1 is based upon the rainstorm of 20 July 1979, which amounted to 1.65 inches at a station a little over a mile to the southwest. This well had not shown a significant response to prior rainstorms; for example, that of 24 November 1978 (1.35 inches). The well is in lacustrine sediments which would be expected to have impervious strata in the interval penetrated by the well. If, however, the rainfall occurred within a brief time period, resulting in flooding, surface water may have entered the gravel pack between the casing and sidewall and could account for an abrupt rise in water level. If this alternative is correct, the low reading made on 20 July 1979 is unexplained. We consider it possible, although unlikely, that this measurement was in error. The small rises in water levels in the other two wells in Ocotillo Wells would also be related in some way to the rainstorm in this alternative. However, water levels in these wells showed less response to previous rainstorms of comparable magnitude.

As mentioned previously, well 7S/3E-23B1 (Fig. 1) in Anza showed large unexplained fluctuations in water level during 1979. The abrupt drop of 8 feet in June is particularly unusual. If the anomalous behavior of well 11S/8E-33P1 in Ocotillo Wells in July is related to the Imperial Valley earthquake, that of -23B1 in Anza may be also.

It should also be noted that none of the wells in the Borrego Springs area, located between Anza and Ocotillo Wells, showed any anomalous water-level changes which could be considered precursors to the Imperial Valley earthquake. By analogy with other wells in the San Jacinto fault zone, the absence of precursory water-level changes in two of the wells could be explained by their relatively shallow depths of 116 and 71 feet; however, if the anomalies in wells 11S/8E-33P1 (Ocotillo Wells) and 7S/3E-23B1 (Anza) are both earthquake precursors, the absence of a precursory water-level change in a third well in Borrego Springs is unexplained, because it is 330 feet deep and located about the same distance from a strand of the San Jacinto fault zone as well 7S/3E-23B1 in Anza.

In summary, certain of the deeper wells along the San Jacinto fault zone have shown anomalous water-level changes prior to earthquakes of M4 or greater occurring along the fault zone. Although the results are encouraging, the data are not sufficiently consistent to confirm that the water-level changes represent actual earthquake precursors.

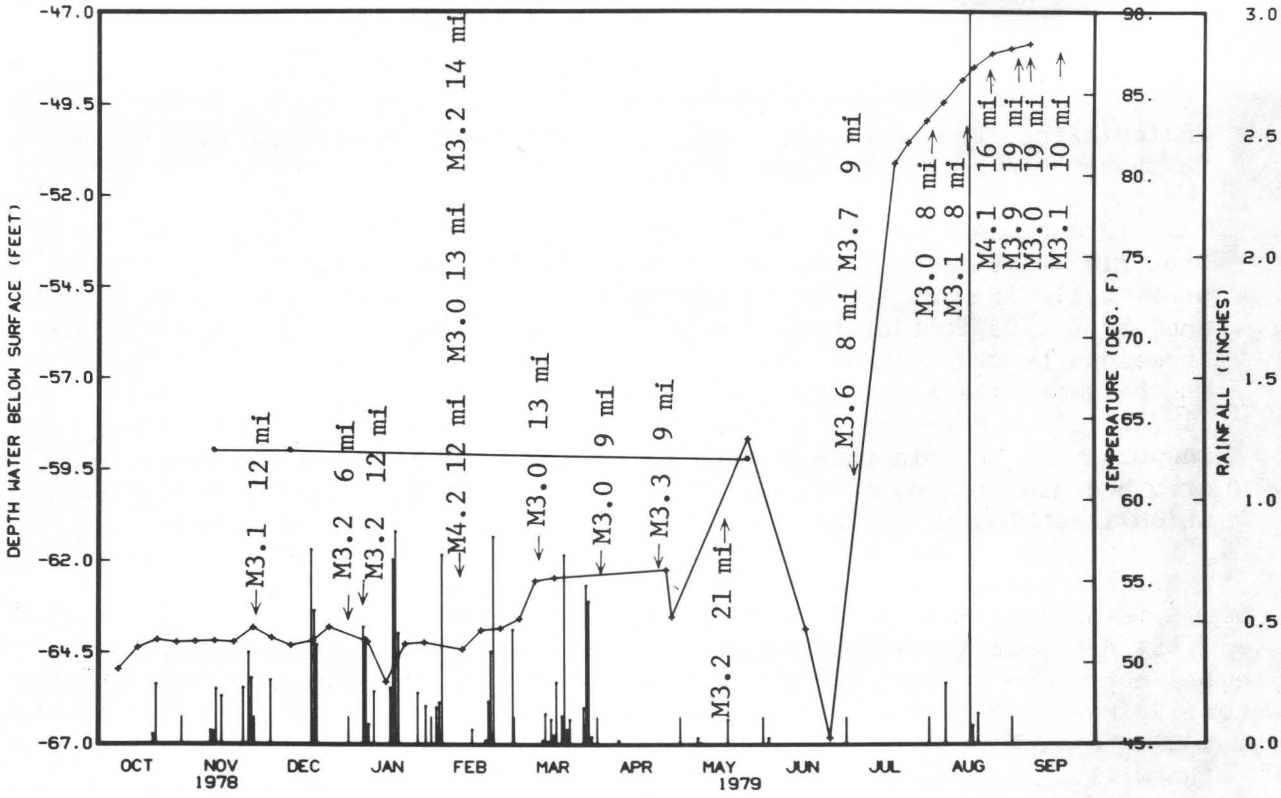

FIGURE 1 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 07S/03E-23B01 AND RAINFALL (.) DURING 1978-1979, ANZA AREA

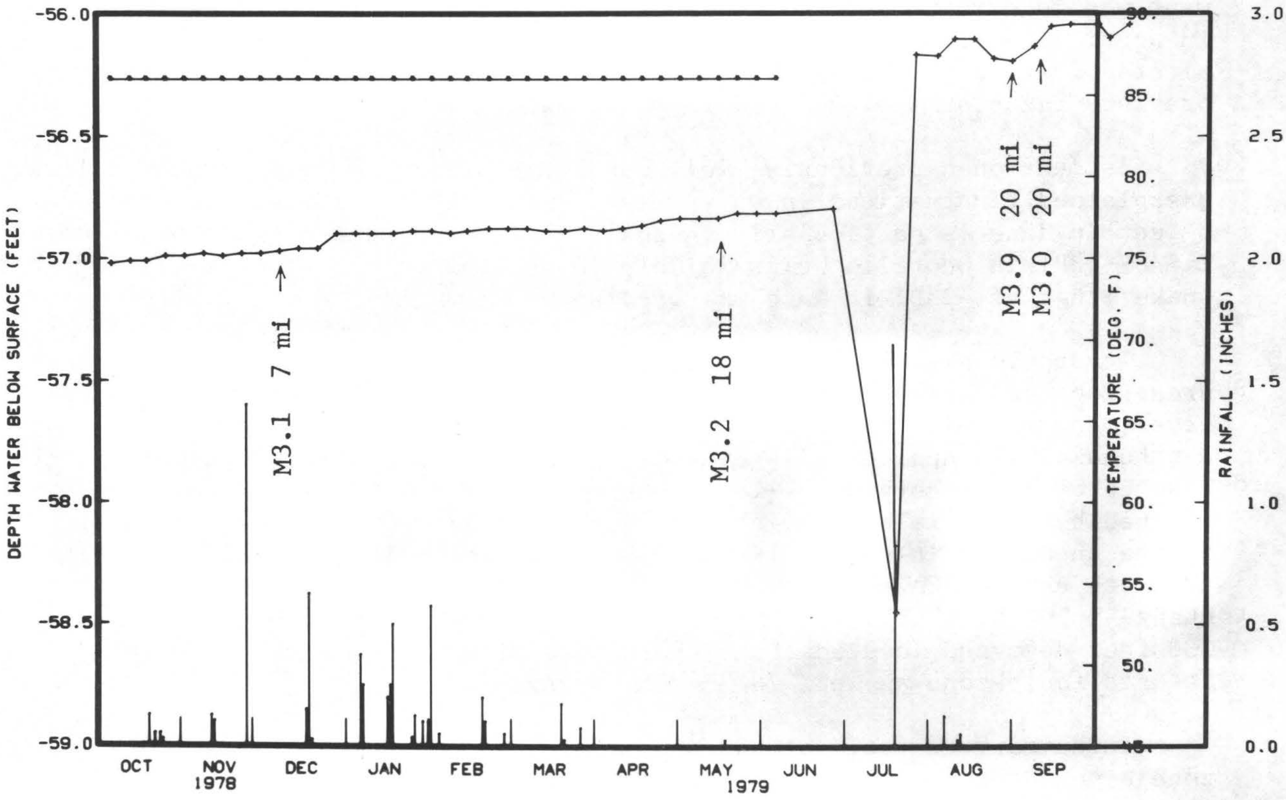

FIGURE 2 - WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*) IN WELL NUMBER 11S/08E-33P01 AND RAINFALL (.) DURING 1978-1979, OCOTILLO WELLS AREA

STOCHASTIC SIGNAL PROCESSING AND ANALYSIS OF WATER LEVEL DATA

#16-08-0001-18210
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Investigation

Explore purposefulness of stochastic signal processing and analysis of water level data using data from presently available wells (U.S.G.S. and Lamar and Merifield).

The ultimate purpose of the overall program is to investigate the usefulness of water well data as an aid in predicting and understanding earthquakes. A major objective of this program is to enhance the usefulness of these raw or unprocessed water level records as precursors to tectonic activity through the employment of modern stochastic signal processing techniques. The goals of this enhancement are:

1) To make the anomalies observable earlier, thus providing lead time for the release of the various stages of the prediction.

2) To clarify the characteristics of what constitutes an anomaly.

3) To change the classification of some wells that might now be thought to be "precursory insensitive" or "unreliably sensitive" wells by techniques which filter out "noise" which corrupts the signal.

4) To assist in the understanding of earthquake mechanisms.

Results

The production processing of data is underway. Multiple regressions have been processed for twelve weeks of Well 5N-12W-4H1 and twelve weeks of Well 5N-12W-14C1. These regressions were processed in one week segments. The percentage of the variance removed from the water level fluctuations for these weekly segments over a period of three months varied between 99% and 93% with an average of 97%.

Figure 1 and Figure 2 show multiple regression processing, which demonstrates 99% removal of the water level fluctuation variance, based on some of the better data. These results are based on Well 5N-12W-14C1 for the week of April 8-15, 1977. Figure 1, a simultaneous plot of the water level, barometric pressure and tidal predictions for Los Angeles Harbor, represents the starting point in the data processing. Figure 2 shows the multiple regression results in the form of residuals, observed and estimated water level fluctuations vs. time.

While progress in satisfying the goals of the project is considered to be excellent, the extensive data that has been processed shows areas where further effort is needed to further enhance the value of the processed data.

For example:

1) While the calibration concerns have been wrestled with at length and partially conquered, further effort toward greater accuracy in our calibration techniques is warranted.

2) The fairly consistent way in which the observed values lead the estimated values of the regression by one to two hours needs to be investigated more fully. It is probable that the tide predictions for Los Angeles Harbor are not completely satisfactory as land tide predictions for Palmdale. Ocean loading effects on the land tides may be responsible for this discrepancy.

3) Some evidence for multicollinearity has been observed in the data. When the regressions are processed in one week segments this multicollinearity results in some variability in some of the regression coefficients. Several methods for dealing with this and establishing more continuity between weekly records are being investigated.

4) Steps are being taken to generate software tools to appropriately characterize time varying well parameters.

Based on the initial structure of the regression function selected, the regressions for each week have been shown to be statistically significant. It has been shown that the variance of the water level fluctuations can be substantially reduced with a confidence level far exceeding 99%. However, as expected in empirical system identification, further study of the model structure is appropriate and is proceeding as planned. It is expected that these additional steps will further enhance the usefulness of the data, thus further increasing the probability of a more certain and earlier capture of any water level precursors that may occur.

Approximately one years' water well level and associated barometric data for well 7S/3E-13D5 at Anza, California, have been digitized and entered into the computer. One and 3/4 years of tidal tables were entered into the computer.

Additional software has been written to facilitate the mass production of regression data. Additional documentation which includes flow diagrams along with more detailed contextual information concerning the software operating system has been generated.

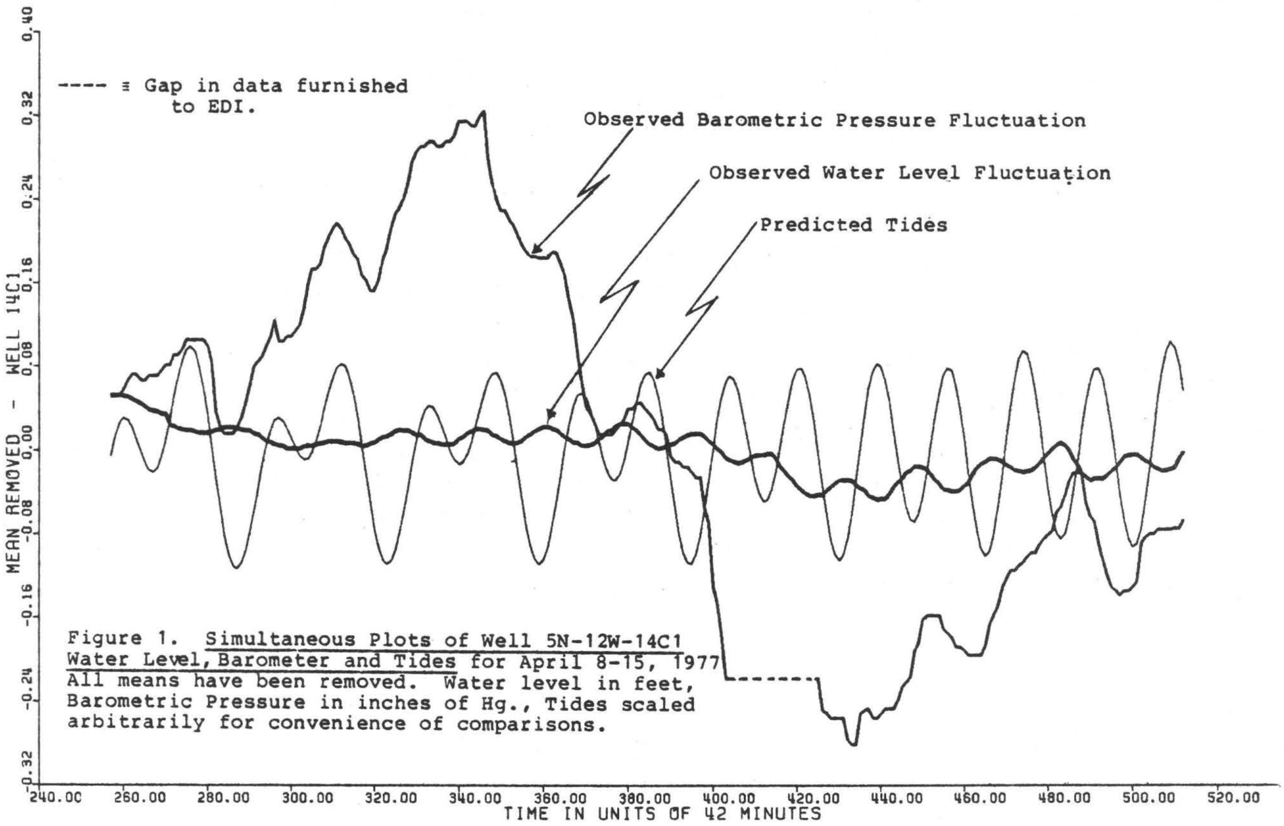

Figure 1. Simultaneous Plots of Well 5N-12W-14C1 Water Level, Barometer and Tides for April 8-15, 1977 All means have been removed. Water level in feet, Barometric Pressure in inches of Hg., Tides scaled arbitrarily for convenience of comparisons.

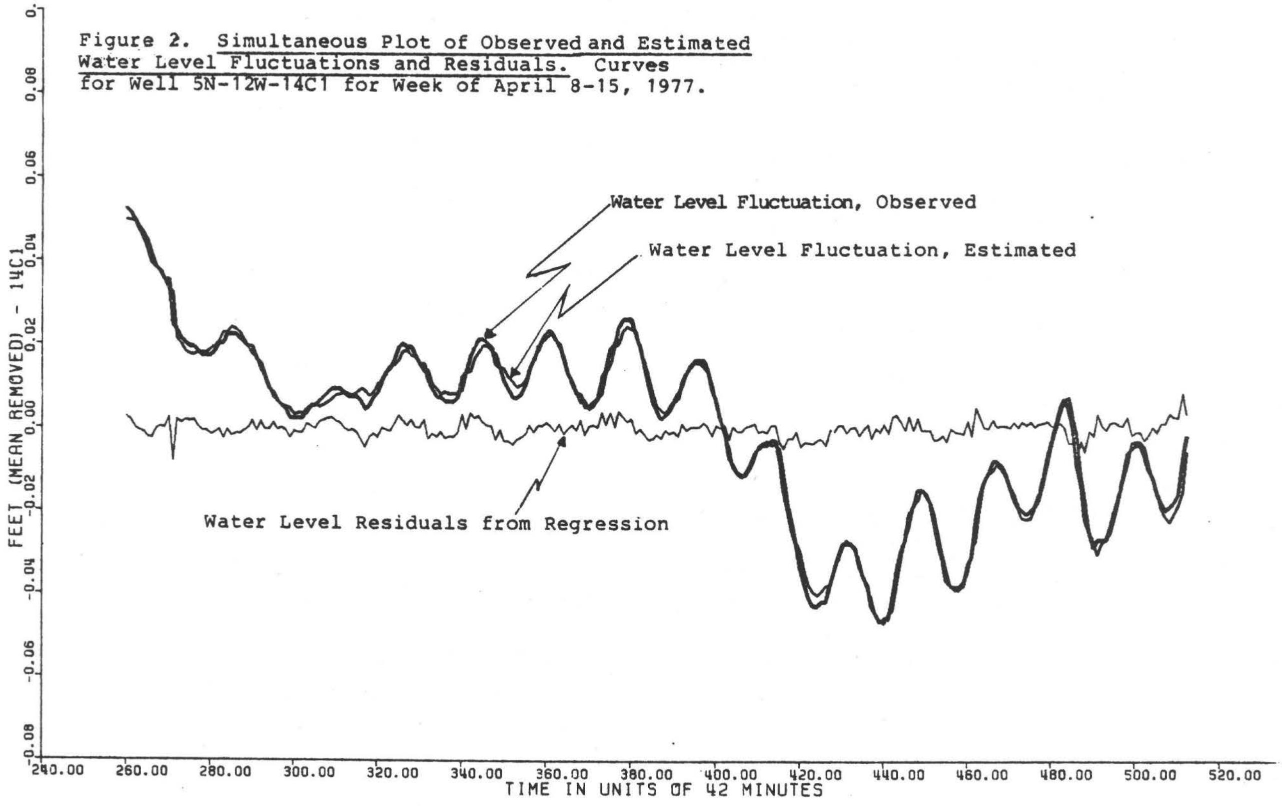

Figure 2. Simultaneous Plot of Observed and Estimated Water Level Fluctuations and Residuals. Curves for Well 5N-12W-14C1 for Week of April 8-15, 1977.

BIOLOGICAL PREMONITORS OF EARTHQUAKES: A VALIDATION STUDY

Contract No. 16784

By: Leon S. Otis, Ph.D, and William H. Kautz, Sc.D.
SRI International, 25 September 1979
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Menlo Park, California 94025
415-326-6200

The goal of this project is to test the long-held popular belief that many types of animals behave unusually just before earthquakes, presumably in response to one or more precursors. To this end a network of volunteer observers of animal behavior has been set up in selected seismic regions of California. The key feature of the reporting protocol adopted requires each volunteer to report on a "hot line" all observed instances of unusual animal behavior. Only reports received prior to an earthquake are counted as positive evidence in support of the hypothesis under test.

During the first 6 months of 1979 the network of observers grew from 262 to 898. Most observers are concentrated in southern Humboldt County; the San Francisco Bay area, north to Santa Rosa and south to Santa Cruz and Hollister; and the northern Los Angeles area, particularly around San Fernando. During this same time period 127 earthquakes occurred having preliminary magnitudes at least 3.0, four of which had magnitude at least 5.0. A total of 946 hot line reports were received. Five hundred seventy-nine were accepted as valid for analysis, after exclusion of post-earthquake calls that either reported pre-earthquake behavior or may have been stimulated by the earthquake itself or by post-earthquake activity.

These earthquake and report data, separated roughly into thirds of the State, have been subjected to a preliminary comparative analysis. When the maximum response distance (from epicenter to observer) and pre-cursory time (days from report to earthquake) were unconstrained, the analysis revealed no marked increase in the number of reports during the several days prior to earthquakes, in comparison with calls received in time intervals not associated with earthquakes. For example, if the intervals between successive earthquakes are bisected, approximately the same number of reports were received during the first half as during the second. The same result was obtained for $M \geq 4$ events only, which were more widely separated in time. On the other hand, only three of the 23 M $\geq$ 4 events occurred anywhere near observer concentrations. Assuming a smaller value of the maximum response distance--40km, say--two of the three show an increase in calls that may on more detailed analysis turn out to be supportive of the hypothesis.

A statistical model and analysis procedure has been created for quantitatively correlating earthquakes and observer reports. It will be computer programmed and applied to all 1979 data by the end of the current project year.

Another computer program evaluates the overall effectiveness of the network, measured in terms of the probability of "capturing" one or more past earthquakes in any given year. This probability is a function of the prescribed maximum epicenter-observer response distance, the minimum magnitude, and the minimum number of observers defining a capture. When applied to earthquakes occurring during the period 1945-1974, the analysis indicates that the existing network has a good chance of testing the main hypothesis within the next two years--for example, with 8 or more observers falling within as little as 10 km of a magnitude 5.0 shock.

Most routine network operations are now automated, including keeping records of the performance of each observer, mailing additional logs, praise and delinquency notices, and preparing weekly and monthly management and statistical reports.

UNIVERSITY OF CALIFORNIA, LOS ANGELES

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Annual Report Summary

Institute of Geophysics and Planetary Physics
Los Angeles, California 90024

Contract #14-08-0001-17686
October 29, 1979

Can Animals Predict Earthquakes?
A Search for Correlations Between Changes in the Activity Patterns of Captive Fossorial Rodents and Subsequent Seismic Events

Durward D. Skiles, Principal Investigator
Institute of Geophysics and Planetary Physics

Robert G. Lindberg, Co-Investigator
Environmental Science Engineering
Laboratory of Fisheries and Marine Biology

Page Hayden, Research Associate
Laboratory of Fisheries and Marine Biology

This project is an experimental investigation of the possibility that certain animals may behave in unusual ways immediately prior to nearby earthquakes. To that end we are continuously monitoring the activity of a small number of individuals of a few species of captive burrowing rodents. At a facility located on the Big Morongo Wildlife reserve in San Bernardino County, California we have the capability of monitoring 20 animals housed individually in running wheel cages in an indoor temperature controlled room and 11 animals housed individually in fabricated burrow systems located out of doors. We are also installing a second burrow system facility in Stone Canyon, San Benito County, California. The latter facility should be operational in November, 1979 and will ultimately have the capability of monitoring 10 rodents.

At the indoor facility on the Morongo Reserve we have been using kangaroo rats (*Dipodomys merriami*) and at the outdoor facility we have recently been monitoring 6 little pocket mice (*Perognathus longimembris*), 4 kangaroo rats and one large pocket mouse (*Perognathus sp.*). These species are native to the area and all individuals were trapped on or near the Reserve. At Stone Canyon we shall monitor 6 *P. longimembris* and 4 larger animals, probably *P. californicu*[s] which is native to the region.

The most significant event of the past year was the swarm of earthquakes centered near Landers, California which commenced about 1218 PST on 15 March 1979. During March the swarm included one event of magnitude 5.2, 6 events of magnitudes 4.0 to 4.9, and 36 events of magnitudes 3.0 to 3.9. The center of the swarm was located a little over 30 km NNE of our Morongo Valley study site and several events were felt at the site with perceptible ground motion lasting as long as 20 seconds. Events associated with the swarm occurred sporadically throughout the remainder of the contract period, and several of those were also felt at our study site.

During the 10 day period immediately prior to the commencement of the Landers swarm, unmistakable activity anomalies were recorded from most animals from both the indoor and outdoor facilities. In most cases these anomalies consisted of increased intensity of activity. In addition, several animals from the outdoor facility suddenly began to appear above ground during midday. Detection of the anomalies required no sophisticated numerical analysis or filtering of the data. All were immediately obvious either from visual inspection of computer printouts of the animal activity data or from graphs of the total daily activity for indivudual animals or groups of animals.

Such dramatic anomalies prior to nearby earthquakes have not been detected for the remainder of the contract period. Prior to, or shortly after, a few magnitude 3 to 4 events minor activity anomalies have been recorded, but many other events of similar magnitudes were not preceded or followed by obvious activity anomalies.

Because of the correlative nature of the present study, it would be premature to conclude that the anomalies observed prior to the Landers swarm were precipitated by the impending seismic events. Temperature records obtained at the outdoor study site show a sudden increase in the daily temperature maxima for the 10 day period preceding the swarm, and it is possible that the unusually warm weather was responsible for the unexpected appearance of animals above ground during midday. Increases and decreases in daily temperature maxima for several weeks after commencement of the swarm also correlate rather well with the midday presence or absence above ground of some animals, but not all.

Presumably, outdoor temperature increases would not be responsible for the increase in activity noted in the indoor temperature controlled facility. However, we cannot rule out the possibility that the increased activity noted in most indoor animals was due to an endogenous annual rhythm, since springtime is normally a period of increased activity in D. merriami related to mating activity and increased availability of food. Since our numerical data recording system was not placed in operation until mid 1978, we must await Spring 1980 before we will be able to assess the latter possibility.

Establishment of a Southern California Geophysical and Data Analysis Center

14-08-0001-16629

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This final summary report covers the period of January 1, 1977 to September 30, 1979.

Goals

1. To enhance and implement an existing computerized earthquake detection and recording system - CEDAR (Caltech Earthquake Detection and Recording).

2. To design, construct, and deploy a data logging and telephone telemetry system for ultra long period grophysical instrumentation - CROSS (Caltech Remote Observatory Support System).

Results

1. CEDAR

CEDAR was initially developed at the Caltech Seismological Laboratory. The system consists of two parts: (a) an on-line detection and recording system and (2) an off-line data processing system.

The on-line part runs on a dedicated Nova 820. Attached to the Nova with 32k of memory are two tape transports, a three megabyte disc storage system, and a 256 channel analog-to-digital converter. 140 lines from seismometer stations located throughout Southern California feed into the computer. These stations are grouped, software-wise, into 30 overlapping subarrays. The detector program constantly monitors the signal from each station maintaining a STA/LTA ratio for each. When this ratio exceeds a set threshold, that station is said to be triggered. If a specified number of stations within any given subarray become triggered within a preset time period, an event is said to have occurred and the data from all stations is then recorded on magnetic tape. All data between events is thrown away.

In order to record the front end of a seismic wave, all data runs through a 30 second "pipeline" and the data moves from the end of the pipeline to the tape recorders when an event occurs.

The off-line part runs on an Eclipse S/230 computer with 32k of memory, two disc drives and two tape transports. It also has an analog-to-digit converter so that it can replace the Nova when necessary.

The off-line system involves a series of steps:

(A) "Prescan" - plotting of all data on any given tape from the on-line system.

(B) "Timing" - picking arrival times with the use of an interactive graphics terminal, those events that an operator decides is an earthquake based on an examination of the prescan plots.

(C) "Location" - the station arrival times are used to compute the hypocenter of the earthquakes, which eventually appears in a catalog.

Although originally conceived and demonstrated by Caltech, CEDAR was fully developed and implemented under this contract such that it is now the operational system for earthquake data processing replacing the older develocorder procedures.

2. CROSS

The CROSS concept was envisioned as an economical way of collecting and retrieving data from remotely sited very long period geophysical instrumentation. It relies on the use of a data logging subsystem referred to as the "Telemetry Interface Module" (TIM) that acquires data from a multiple number of nearby instruments, stores this data and transmits the acquired data upon demand over standard direct-dial voice-grade telephone lines.

Data transmission is initiated by a central computer system located at the Caltech Geophysical Data Center. Although the system was developed on a Data General Eclipse S/230 acquired for this purpose (same system used by CEDAR), it currently runs on a PR1ME 500 computing system.

All control of the CROSS system relies in the central computer software. When a set of TIM units is to be interrogated, the program fetches a TIM unit entry from a station list that is normally resident in a disc file. This station list consists of an entry for each TIM site. Each entry consists of the station ID, a control word, and a telephone number. The program uses the telephone number to initiate the call-up sequence using an auto dialer. When the hardware has established a successful linkup with the target TIM, the central computer commences to make requests of the TIM. The nature of these requests are determined by the control word referred to above.

The 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. Cards that currently comprise a TIM 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. Three board set for telephone telemetry: modem controller, modem.

Nineteen TIM units have been built and are being deployed as the recipient sites become ready.

Establishment of a Southern California Geophysical Data and Analysis Center

14-08-0001-17642

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(203)795-6811

This final summary report covers the six-month period from April 1, 1979 to September 30, 1979.

Goals

1. To support the data collection and processing activities of the CEDAR (Caltech Earthquake Detection and Recording) system and CROSS (Caltech Remote Observatory Support System).

Results

1. CEDAR

CEDAR operations although developed and supported by this contract and its immediate predecessor (Contract #14-08-0001-16629), is now an element of the joint USGS-Caltech SCARLET system (Southern California Array for Research on Local Earthquakes and Teleseisms). As such its product is a component of the results produced by the contract "Southern California Seismic Arrays", contract #14-08-0001-16719. The result of this effort during this reporting period was the recording and processing of 2,849 earthquakes effecting a digitized data base of seismic events stored on 45 "Archive" 800 BPI magnetic tapes.

2. CROSS

This contract supplies operational support for CROSS developed under the predecessor contract (given above). During this reporting period eight TIM units have been deployed. They are as follows:

Site Location	# Chan. in use	Type of Measurements	Principal Investigator
Kresge Lab.	6	tilt, gravimeter	Test site
Caltech Campus	6	tilt	T. Ahrens
Palmdale	8	tellurics	T. A. Madden
Hollister	8	tellurics	T. A. Madden
Buck Canyon	1	strain	B. Clark
Valyermo	1	strain	B. Clark
Bouquet Reservoir	1	gravimeter	L. Teng
Valyermo	1	water well	D. Lamar/ K. McNally

The data at these sites is collected once a day via the telephone telemetry polling procedure and is being accumulated as a data base on the Caltech Seismological Laboratory PRIME computing system. The data is available externally via a modem port on the computer system but the current method of data delivery for non-Caltech investigators is by use of magnetic tape.

P.C.

SUMMARY OF TECHNICAL REPORT

Numerical Methods in Seismology: Ray-Tracing and Inverse Problems

Contract No. 16777

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(213) 795-6811

July 25, 1979

Ray tracing codes for two and three dimensional, heterogeneous media have been completed. Piece-wise continuous media has also been delt with in 2D and this code has been used as a base for a general inversion algorithm with which we can recover velocities, hypocenters and reflectors by using travel time data. Extension of these procedures to three dimensions is under development.

Minicomputer Systems Development

9970-02118

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Menlo Park, CA 94025

Investigations

The 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.

A minicomputer-based seismic data processing system has been developed to process local earthquakes from the USGS central California network's analog tape recording system. The goal of the system is to provide preliminary hypocenters and associated waveform data on a routine basis within 24 hours of the occurrence 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 four 14-track on-line analog tapes. Information is recorded on those tapes in Frequency Division Multiplexing format (FDM) which allows up to 112 stations per tape.

The data flow within the system is controlled by an operator who, with the help of computer-updated files, invokes the appropriate processor as the events pass through the system. The current processing status of all events is accounted for from the time of the request until the event has been either copied onto a digital archive tape or processing has been discontinued.

The events are detected initially either by manually scanning microfilm or by an independent on-line earthquake detection system which produces request cards for the first stage of the system. The processing consists of reading the request cards, creating the dub library tape, selecting the analog channels to be processed, digitizing and displaying those channels, interactively picking first arrivals and other seismic parameters, locating the hypocenters, and creating a digital archive tape of the events.

Results

During the report period, the initial processing design was extensively revised. The revised process is now operational and routine processing of central California earthquakes has begun. One of the key elements, the SELECT program, which selects the stations to be digitized, was completely rewritten. A major effort by Bill Ellsworth and Paul Reasenberg has made the History File/Dub Control File/SELECT portion of the system work smoothly.

A dub verification program was written by Bob Haken. This program compares dub library files with dub requests and detects discrepancies. It has proven to be very effective.

A seismic trace plotting program has been written by Bob Haken to plot data on the Varian plotter. Seismic trace files from the earthquake processing system provide the input data.

The "A" and "B" Eclipes are now connected as the result of installing an IPB (Inter-Processor Bus). This allows greater flexibility in the two CPU's accessing the 92 Mb disk. All dubbing is now done on the "C" Eclipse.

Department of Earth and Planetary Sciences
M.I.T.
Cambridge, Mass.

Development of a Quantitative Model of Stress in a Seismic Region as a Basis for Earthquake Prediction

Summary of Semi-Annual Technical Report April 1979-Oct. 1979
Contract No. 14-08-0001-18205

Principal Investigator: Keiiti Aki
(617) 253-6397

Goal

To determine spatio-temporal distributions of incremental stress in the lithosphere as a basis for quantitative studies of stress induced earthquake precursors.

Investigations

Geodetic inverse problem is formulated as TX=Y where T is an operator, X represents unknown displacements and forces, and Y represents known displacements and forces. This is a problem similar to the Canchy's boundary condition for Elliptic equations. Three dimensional finite element scheme provides a discretized operator T. Geodetic data such as triangulation, trilateration and levelling survey data provide, together with a stress free condition on the free surface, the Canchy's condition for our problem.

Results

A special purpose three-dimensional finite element scheme using an eight-nodes isoparametric element was developed. This finite element scheme was adopted because of its particular suitability to the geodetic network.

To avoid instability, additional constraints are introduced by the free surface condition at internal points where displacements are fixed by interpolation. This, together with balancing of internal forces, make the problem well-posed.

A matrix sorting and eigenvalue decomposition program based on Jacobi rotation give a psuedo-inverse (or generalized inverse) operator of T.

The program was successfully tested using hypothetical data such as uniform shear strain and buried point force.

A preliminary study based on actual data from Southern California geodimeter network (Thatcher, 1979, 1976, Savage et. al., 1972) and levelling data (Castle et. al., 1976) during the Palmdale uplift 1959-1972 is now in progress.

Thatcher determined from geodetic data uniform right lateral shear strain of $\dot{e}=0.36$ μstrain/year in the direction N11°E in block ABEF (Fig. 1) and $\dot{e}=0.69$ μstrain/year in the direction N136°E in block BDCE. From these strains, we obtain horizontal displacements at nodes A, B, C, D, E, and F while vertical displacements are obtained directly from contours of levelling map given by Castle (Fig. 1). Linear time dependence of the uplift is assumed.

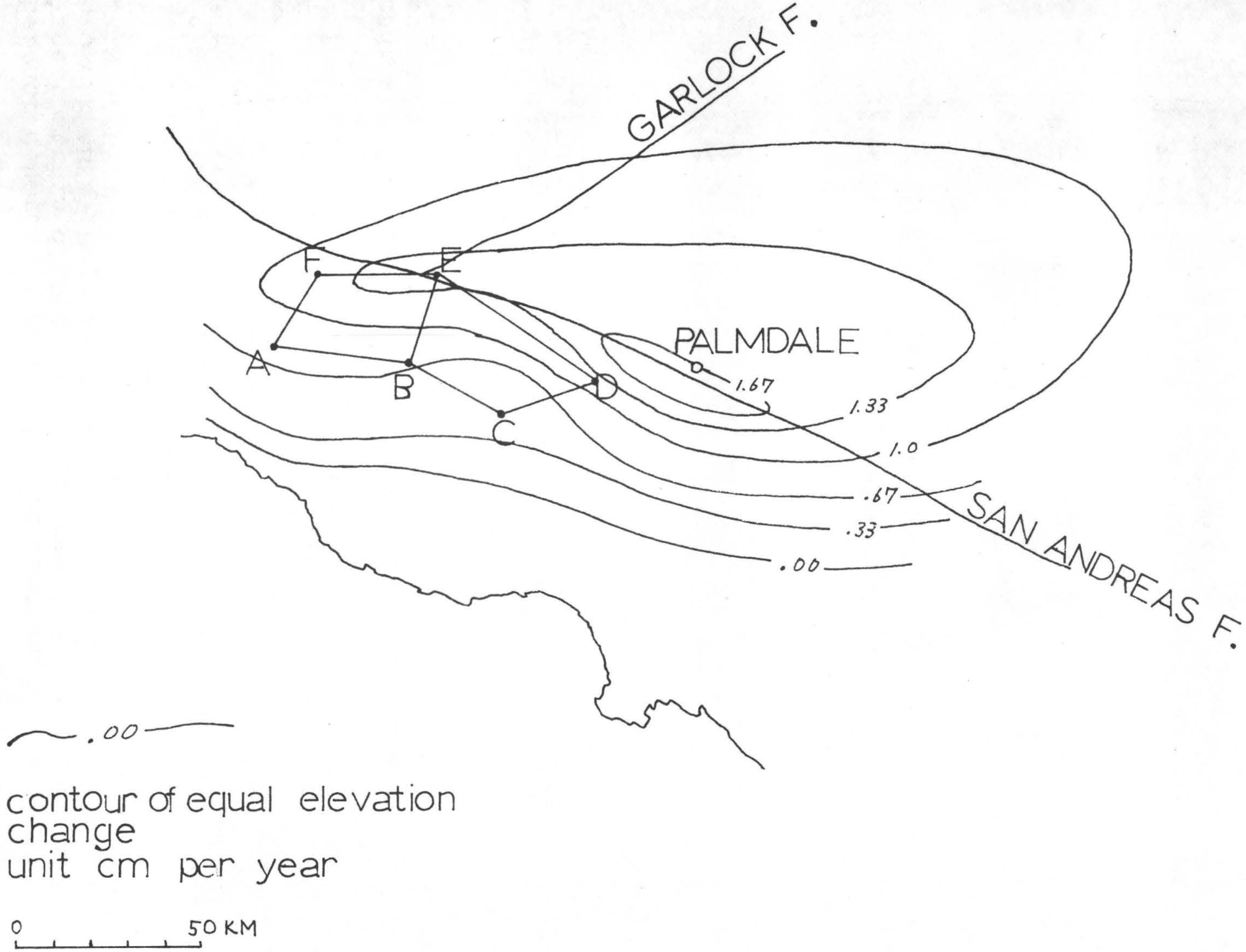
The axises and magnitudes of principal stresses at the depth of 5 KM below the center of each block are shown in Fig. 2. The result is preliminary, but it is interesting to note that the state of stress at the depth of only 5 KM can be significantly different from the horizontal stress measured on the surface.

Report

Ikeda, K. Three dimensional geodetic inversion method for stress modelling in the lithosphere (Abs.) EOS Trans. AGU, 60, 316, 1979.

FIG.1 CALIFORNIA GEODIMETER NETWORK AND PALMDALE UPLIFT 1959–1974

P.D.



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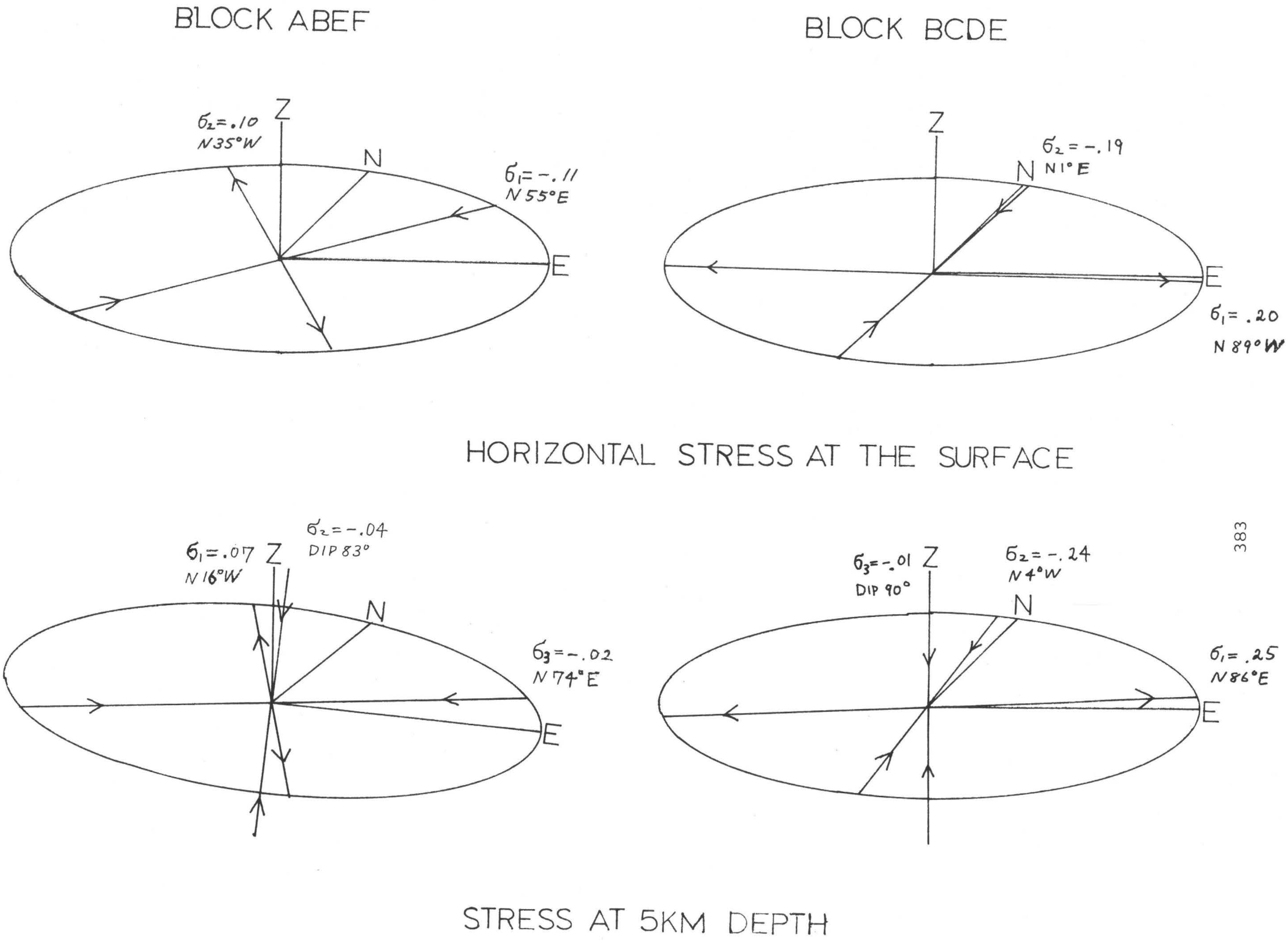

FIG.2 PRINCIPAL INCREMENTAL STRESS

THEORETICAL MECHANICS OF EARTHQUAKE PREDICTION

9960-02115

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Investigations

1. Constructed two-dimensional elastic models to study interaction of faults in the Hollister, California area. If models are consistent with past seismicity, fault creep and geodetic data, the models will be used to estimate parameters of future earthquakes.

2. Calculations were made to estimate the effect of melt phase geometry on velocity, attenuation, and dispersion in partially melted rocks. The rock models consisted of an elastic matrix containing a dilute distribution of viscous melt inclusions.

Results

1. Two kinds of model simulations were made to help clarify the relations among seismicity, fault creep, the orientation of fault strands, and the regional principal stresses. In the first model, fault stress obeys a pressure dependent "friction" law. With no slip softening, increasing regional stress induces fault slip changes that are partially consistent with observed creep records. With slip softening, the model in addition simulates certain observed earthquake sequences.

In the second model, fault slip is imposed as a boundary condition. Fault slip vs. time at each position is assumed to be a function of the number (not moment) of nearby earthquakes. Good agreement between plots of cumulative number of earthquakes and creep records justifies this procedure. Some past earthquakes are successfully anticipated by earlier computed stress changes, and observed geodetic line length changes are partially consistent with computed changes.

2. The models predict that melt distributed as thin films on grain faces causes the greatest decrease in velocity and increase in attenuation for a given melt fraction. However, the interpretation of seismic observations is not unique, because similar effects can be produced by larger fractions of melt distributed as tubes along grain boundaries. An important result is that significant relaxation of the bulk modulus should be expected whenever melt is present, although the relaxation time may lie outside of the short period seismic body wave band.

Mavko, G., 1979, Frictional attenuation: an inherent amplitude dependence, J. Geophys. Res., 84, B9, 4769-4775.

Mavko, G., and A. Nur, 1979, Wave attenuation in partially saturated rocks, Geophysics, 44, 2, 161-178.

Mavko, G., E. Kjartansson, and K. Winkler, 1979, Seismic wave attenuation in rocks, Reviews of Geophysics and Space Physics, 17, 6, 1155-1164.

Mavko, G., 1979, Velocity and attenuation in partially molten rocks, Submitted to J. Geophys. Res.

Mavko, G., The effect of melt phase geometry on velocity and attenuation, Conf. on Seismic Wave Attenuation, Stanford University, (abs.)

Mavko, G., and W. D. Stuart, 1979, A model study of interacting faults in the Hollister area, EOS, (in press) (abs.)

Stuart, W. D., and G. Mavko, 1979, Earthquake instability on a strike slip fault, J. Geophys. Res., 84, 2153-2160.

Stuart, W. D., 1979, Quasi-static earthquake mechanics, IUGG U. S. Nat'l Report 1975-1978, Rev. Geophy. Space Phy. 17, 1115-1120.

_____, 1979, Strain softening instability models for earthquake precursors, UNESCO Conf. on Earthquake Prediction, 1979, in press.

STUDY OF RESERVOIR INDUCED SEISMICITY

Summary

August 1979

Contract No. 14-08-0001-16809

by

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The number of impounded reservoirs having maximum water levels greater than 92 m (deep) and/or maximum water volume greater than 10^{10} m^3 (very large) has increased from approximately 60 in 1960 to more than 230 in 1979, and is projected to increase to approximately 275 by 1985. Projections from the past 20 years suggest that at least 10 more cases of reservoir induced seismicity are likely to occur prior to 1985 at deep and/or very large reservoirs alone. In the past, some RIS occurred in areas of low historical seismicity where the design of dams had not fully anticipated an earthquake as large as that which occurred; therefore, the potential for such damaging reservoir induced earthquakes is also increasing.

The impoundment of many reservoirs has significantly influenced the temporal and spatial patterns of earthquake occurrence in the vicinity of the reservoir. For some of the more than 75 reported cases of reservoir induced seismicity, the seismicity is clearly related to reservoir impoundment and water fluctuations, whereas for others it is not. For more accurate evaluations of the theoretical mechanisms of reservoir induced seismicity, of the methods to mitigate potential effects, or of the prediction of occurrence of reservoir induced seismicity, those cases of actual reservoir induced seismicity must be distinguished from those cases where reported seismicity most likely was not related to the reservoir impoundment. In this study, the influence of the reservoir on local macro- and micro-seismicity has been evaluated for each reported case of reservoir induced seismicity. Where post-impoundment seismicity had a demonstrable spatial and/or temporal relationship to the reservoir, the case for reservoir induced seismicity is classified as accepted. Where it was clearly established as being unrelated to the reservoir, the case is classified as not reservoir induced seismicity. Where the relationship is unclear because of insufficient data, the case is classified as questionable reservoir induced seismicity. Of the 75 or so reported cases of reservoir induced seismicity, 64 were considered in our classification; 45 were assessed to have accepted reservoir induced seismicity, 7 were assessed not to have reservoir induced seismicity, and 12 were assessed as questionable. Of these 45 cases of accepted RIS, 16 were recognized as accepted reservoir induced seismicity at macro- and micro-seismicity levels, 14 were recognized at macro levels only, and 15 were recognized at micro levels only.

A population of 234 deep and/or very large reservoirs having maximum water depths greater than 92 m and/or maximum water volume greater than 10^{10} m^3 was selected to investigate the probability of occurrence of reservoir induced seismicity. There are 29 accepted cases of reservoir induced seismicity among these reservoirs and the prior probability of RIS is 0.12. Data on the depth, volume, regional stress regime, and predominant rock type of reservoir geology were collected for each reservoir. Data on active faulting in the vicinity of the reservoirs were obtained in some cases, but data were insufficient for the statistical analysis. Additional data were obtained on a large number of engineering, geologic, and seismologic aspects of many of these reservoirs, but were not used in the statistical analysis.

A multivariate probabilistic model was constructed for the conditional probability of reservoir induced seismicity at a reservoir characterized by its depth, volume, stress, rock type, and faulting. The analysis suggested a higher occurrence of reservoir induced seismicity with increasing depth, with increasing volume, among reservoirs with predominantly sedimentary rock underlying the reservoir, and among reservoirs in a strike-slip (shear) stress regime. Of these four variables, depth and volume were most strongly correlated with reservoir induced seismicity. A sensitivity analysis indicated that these conditional probabilities are very sensitive to changes in data classification among the reservoir induced seismicity cases because of the relatively small size of the reservoir induced seismicity data set. This is particularly true for the regional stress regime and geology data; therefore no strong conclusions about the relationship between reservoir induced seismicity and the regional stress regime or geology were drawn.

A review of theoretical models of reservoir induced seismicity, including fluid-filled models, show that models have been used to successfully predict ground deflection and can explain seismicity occurrence during initial filling and observed delays in the occurrence of seismicity associated with small changes in water level. The fluid-filled models allow for much larger stresses to be generated at depth either by pressure increase or by zones of low permeability. These models also explain the occurrence of seismicity away from the center of the reservoir.

Models of the stresses created by the filling of reservoirs suggest that reservoir filling does not provide sufficient stress to initiate new fracturing and must trigger the release of stress along pre-stressed faults. This implies that displacements resulting from reservoir induced earthquakes on such pre-stressed, tectonically active faults must have occurred as a result of the present or active tectonic stress regime. The existence of active faults was investigated by field reconnaissance at 6 of the 11 reservoirs that had induced earthquakes of maximum magnitudes greater than or equal to 5. Of these 11 reservoirs, 9 have evidence indicating active faulting near the reservoir and two probably have active faults, although the evidence is not conclusive. The results of these field reconnaissance studies suggest that active faults are present within the influence of reservoirs that have triggered earthquakes with magnitudes greater than or equal to 5 and that these reservoirs have not triggered surface displacement along inactive faults.

"A Seismic Spectral Discriminant for Reservoir Induced Earthquakes"
Contract No. 14-08-0001-17713

by
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Project Summary

The specific problem addressed by this research is the identification of areas where reservoirs could induce significant seismic activity. An ω-cube high frequency spectral slope was found to be characteristic of earthquakes associated with two southeastern United States reservoirs which have induced seismic activity. In contrast, microearthquakes in the Folded Appalachians have an ω-square high-frequency spectral slope in areas where reservoirs have not induced earthquakes. Hence, in the southeastern United States the spectral slope may be a viable discriminant for identify areas susceptable to induced seismic activity. In this study the generality of the spectral discriminant is to be tested for earthquakes of other reservoir areas.

Fundamental to this study is an understanding of the theoretical basis for the discriminant. Source models have been reviewed and summarized as to their predicted high-frequency spectral slopes. The ω-cube high-frequency decay is typically associated with transsonic rupture velocities on existing plains of weakness. The ω-square high-frequency decay is typically associated with subsonic rupture velocities on fault plains which may shown premature arrest of slip.

Published reports of spectral slopes have been examined in the hope of discriminating ω-square or ω-cube areas. The remainder of this study will be concerned with testing the generality of the ω^{-3} high-frequency spectral characteristic in specific reservoir areas. Measured slopes will be compared to geology, regional tectonics, and spectra, when available, of near-by tectonic earthquakes.

The sparse availability of data of sufficient quality is expected to be the major difficulty to overcome in this study. Propagation effects and instrument response limit the data that can be used for high frequency spectral computation. In an exercise which involve computation of attenuation recording instrument saturation and frequency response the characteristics of data which may be successfully analyzed are identified. For WWSSN data recorded at a magnification of 50 k the high-frequency slope can be computed for typical magnitude 3 to 3.5 events recorded in the range of 40 to 180 km provided the Q value is greater than 800. In general, the success of the measurement of spectral slope (and hence of the discriminant for induced seismic activity) depends on the Q value for the data region if traditional and existing recording systems are to be used. Q values for the Georgia-South Carolina Piedmont area will be calculated. Using the method of spectral ratios, preliminary indications are that $Q_p > 600$ for local events.

Possible reservoir data areas have been tabulated. Of these, only a few may have data which could be analyzed for the high-frequency spectral slope. Data from these areas are being requested.

Crustal Loading and Induced Seismicity at the Yacambu Reservoir, Venezuela

14-08-0001-17644

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R. Bilham, and A. J. Murphy
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Summary of Final Report

Investigations

1. The effect of filling a reservoir at the base of which a weak fault zone exists has been studied using finite element modelling.

2. Horizontal wire strainmeters with single catenaries up to 45 m long have been developed and tested for use in crustal deformation studies. Three 20 m instruments have been installed near the Bocono fault.

3. A new micrometer capacitance sensor for long baseline tiltmeters has been developed for use near the Yacambu Reservoir.

Results

1. The effect of reservoir loading is to depress the reservoir floor and hence to extend the surface locally. Extension is also expected from the lateral pressure exerted on the dam and the mountainside by the reservoir as the water level rises. We have examined these effects numerically in an attempt to predict the magnitude of horizontal strain resulting from reservoir impounding. Opposing this lateral extension are compressive lithostatic stresses arising from the surrounding mountains and tectonic stresses within the region. The latter are assumed to be compressive, although no measurements of direction and magnitude have been made. We have incorporated a zone of elastic weakness to represent a 100 m wide fault zone that exists near the submerged foot of the dam and extends some tens of km in each direction along the axis of the reservoir. An important result is that the fault zone is subjected to the highest tensile strains.

2. WYP15 carbon fiber strainmeters were found to have good stability compared to invar wire instruments and compared to instruments using early carbon fibers manufactured from discontinuous polyacronitrile. An improved tensioning system enables instruments to operate in high noise environments through the use of silicone fluid damping. The resulting instruments can be operated at lengths up to 50 m using single catenary fibers and possibly up to 500 m using fluid immersion methods. Three 20 m strainmeters were installed in a linear array approximately 2 km south of the Bocono fault zone in June.

3. The use of a single graphite fiber to index water height in a long baseline water-tube tiltmeter will simplify the manual operation of tiltmeters at Yacambu. The 8 μm diameter fiber is fixed using conductive epoxy or silver paint to the end of a digital micrometer that reads to 1 μm. The micrometer is rotated until a beep from an acoustic warning device indicates that the fiber is touching the water surface, and a reading is taken. The small diameter of the fiber results in less than 25 μm of meniscus formation and the measurement may be repeated rapidly and with good repeatability. The "absolute" height value obtained from this system is in addition to a continuous 1 μm/mV signal from a capacitance detector built into the base of the unit. The sensors have been developed to detect tilts within the Yacambu dam abutment. The tiltmeters will be between 100 m and 500 m length and use a half-filled water tube as a horizontal datum.

Reports

"Improved carbon fiber extensometers", E. Hauksson, J. Beavan, and R. Bilham, EOS, 1979.

"The Yacambu Experiment - A description of seismicity, crustal-deformation and pore pressure measurements in the vicinity of the Yacambu Reservoir", Report prepared for FUNVISIS and FUDECO, R. Bilham and D. Simpson, June 1979.

PROJECT TITLE: Geological and Geophysical Studies of Induced Seismicity at Nurek Reservoir

Contract Number: USGS-14-08-0001-17707

PRINCIPAL INVESTIGTORS: C. Keith, D. Simpson, W. Alvarez

INSTITUTION: Trustees of Columbia University in the City of New York

TELEPHONE NUMBER: 914-359-2900

Investigations:

1. An eight station, high-gain, telemetered seismic network has been in operation around Nurek Reservoir since 1975 as part of the Joint Soviet-American Exchange Program on Earthquake Prediction. The data produced by this network has been analysed up to the beginning of 1978. This time period includes the raising of the water level from 100 to 210 metres in 1976.

2. To gain a better understanding of the recorded seismicity the tectonics of the Tadjik Depression and the setting of the Nurek area in this framework has been studied. Geological field mapping of the reservoir area has been carried out.

Results:

1. Seismicity. The first filling of the reservoir to 100 metres occurred in 1972 before the installation of our network and was accompanied by a pronounced increase in seismicity. The seismicity during this filling episode appears to have begun about 10 km to the southwest of the reservoir and migrated towards it. The data from 1975 and early 1976 from our network indicates that some activity was still occurring beneath the reservoir at this time but not at an appreciably greater level than in the surrounding region.

The filling of the reservoir from 100 to 210 metres that began in August 1976 was accompanied by a pronounced increase in seismicity. The locations of the events define several distinct, short (5-10 km) sections of active fault zones with depths to about 7-8 km. Remarkably, four of these fault zones are connected in a "zig-zag" pattern (Figure 1).

Along the southeast shore of the reservoir, the seismicity aligns up along the strike of the Gulizindan fault which is seen on the surface. The northern end of this fault zone is terminated by another fault zone which strikes at 90° to it. Some of the seismicity to the north and east of the reservoir appears to fall on the Ionaksh fault, one of four known thrusts in the Surkhu Mountain range. Figure 1b shows the fault zones inferred from the seismicity.

2. Motion on the faults. The fault zones are numbered in Figure 2. On fault zone I composite fault plane solutions define thrusting motion. There is some ambiguity as to whether the fault plane dips to the southeast or northwest. Cross-sections of the seismicity on this fault zone prefer the dip to the southeast. Fault zone II has strike-slip motion with part thrust. Fault zone II has thrusting on a steep plane dipping to the southeast. Fault zone IV has almost pure strike-slip motion.

Fault plane solutions for zones V, VI and VII have yet to be worked up. From the inferred deformation of the region and the known thrust faults that exist near zones V and VII, these probably are thrust faults with dips to the southeast. The cross-section for fault zone V is in agreement with this whilst that for zone VII is too poorly constrained to make a judgement. From the inferred thrusting motion on Zone V, the 90° difference in strike between zones V and VI and the spatial coincidence of zone VI with the offset in the river (Figure 1b), fault zone VI would appear to have strike slip motion. It will be interesting to see if the fault plane solutions bear this out.

3. Temporal variations in seismicity. In early 1976, there was some activity on fault zone II or III or both (the data are not accurate enough during this time to distinguish). Some activity occurred on the northern section of I and V and maybe VI. The level of activity, however, appears not to be appreciably greater than in the surrounding region. The filling of the reservoir in August 1976 caused a profound change in the level of activity and in its location. Fault zones II and III became highly active at the beginning of the impounding episode. The activity on zone II decreased with time until by December of that year it has practically ceased. Fault zones I and IV became active about 2 months after the beginning of the impounding episode. On zone I the activity was concentrated in two very active "hot spots" whilst on fault zone IV there was a trend in activity towards the south with time.

Fault zone V became active at the beginning of the inducing episode, but not with the same intensity as on the fault zones near the main body of the reservoir. At the beginning of the filling episode the activity was concentrated in one "hot spot", but with time also occurred along the length of the fault zone.

The time history on fault zone VI is rather interesting. There may have been some activity at the beginning of the filling episode on the part where it reaches the river. The locations however, are not sufficiently accurate to rule out the possibility that this activity was on the northern end of zone V. The rest of this fault zone did not show activity until about four months after the filling episode. So, either (a) the activity is unrelated to the filling of the reservoir, (b) the porosity in this area is very low leading to a long delay in the pore pressure effect, or (c) it was only after this length of time that the water level was 20 km upstream from the deepest part of the reservoir sufficiently high for a sufficient length of time to change the seismic regime on this fault zone.

4. Relation to geology. In our last report on this contract the importance of salt tectonics in the deformation of the area was noted and the resemblance of some of the geological features to those in a fold and

thrust belt pointed out. The inference was made that the seismicity was occurring on pre-existing structures formed during the thin-skinned deformation of the area. The thrust fault zones were inferred to be imbricate thrusts and the strike-slip fault zones to be tear faults, though some problems of this interpretation were noted.

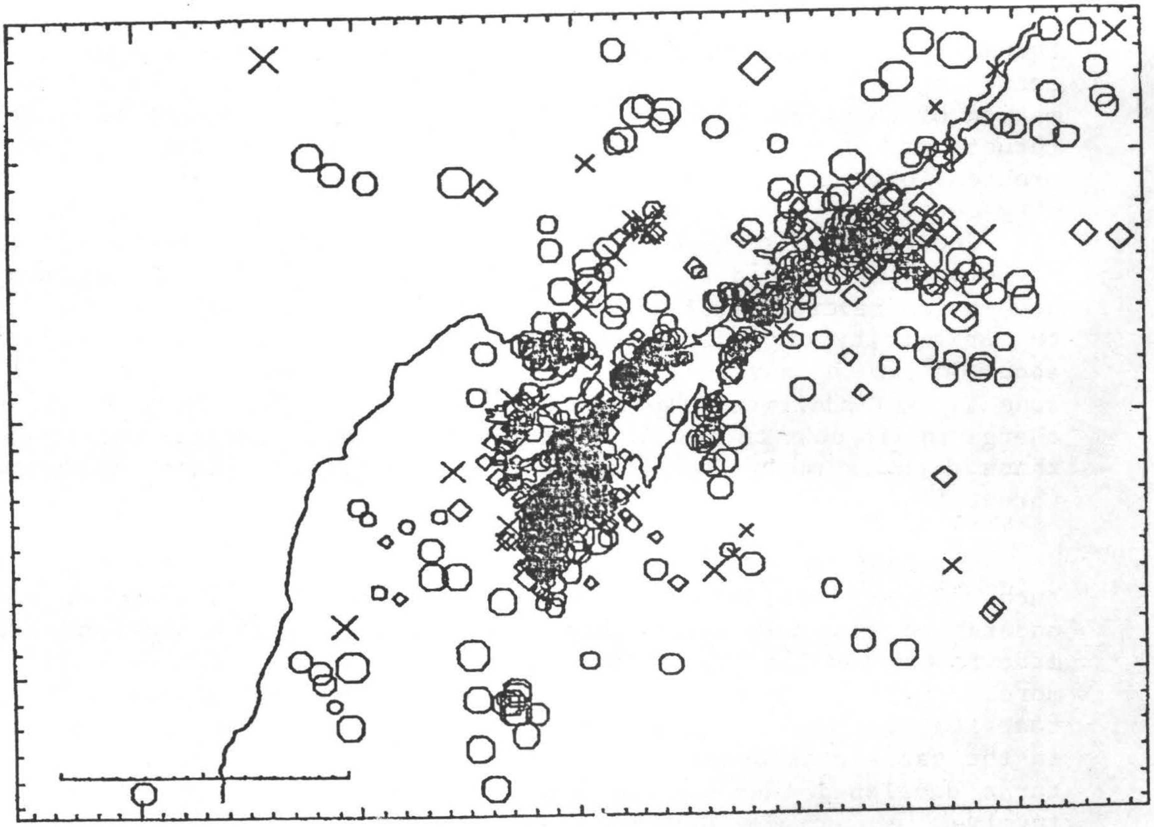
Geological field investigations carried out this summer may point to revisions in these ideas. The most serious problem is the steepness of the high-angle reverse faults. Examination of the Gulizindan thrust (on which the seismicity of fault zone V was proposed to occur) revealed a dip of about 30° at the surface. This is a much shallower dip then that of fault zone V. In addition, fault zone III has a dip of about 70-80° with no change in dip down to 7-8 km where the seismicity ceases. The steepness of these dips is much greater than that usually associated with imbricate thrust faults.

Examination of the area around the main body of the reservoir revealed such intense folding that there is a large room problem in trying to understand its deformation history. Balanced cross-sections are being made to try and resolve the problems. The deformation of the area is much more complex therefore than such simple labels as imbricate thrusts and tear faults suggest. Thin-skinned tectonics no doubt played a large part in the earlier deformation processes of the region. However, the structures developed then appear not to have been left intact, but further involved in a complex deformational process since then. Indeed, there is a distinct possibility that some of the features defined by the seismicity represent new faults, created as a response to the impounding of the reservoir.

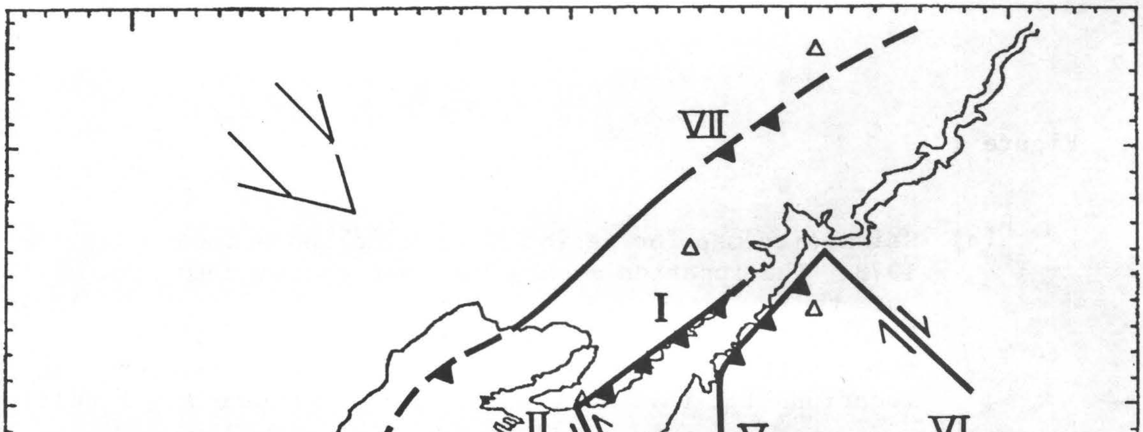
Figure 1

(a) Seismicity map for period for the period October 1976 - February 1978. The location accuracy is not constant in time or throughout the network (station location are shown in Figure 1b) leading to most of the scatter observed. Data for early 1976 is not plotted because only 3 or 4 stations were operating and the locations for this time period would obscure the lineations.

(b) Map showing the seismic stations (triangles) and the 1000 ft contours of the reservoir which the final water level will reach. Continuous lines represent fault zones inferred from the seismicity. Broken lines represent known geological faults.



(a)



(b)

Induced Seismicity, Earthquake Prediction and Crustal Structure Studies in South Carolina

Contract No. 14-08-0001-17670

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1. Induced Seismicity at Lake Jocassee (Jan.-Sept. 1979)

Seismicity at Lake Jocassee has been monitored since October 1975 using portable seismographs and recently three permanent stations. In the reporting period one significant event occurred, and is described below.

The Jocassee earthquake of August 26, 1979

A magnitude M_{bLg} 3.7 (BLA) earthquake occurred at Lake Jocassee, at 01h:31m (UCT) on August 26, 1979. This MM intensity VI was felt over 15,000 sq. km. and was located within 3 km from the Jocassee dam and power plant. Four portable seismographs were added the same day and in the following three weeks, 25 aftershocks were recorded.

The main shock (Number 13) occurred in a 'gap' between earlier larger events (Figure 1). The aftershock zone covered the area of earlier large events (Numbers 3 and 7) but were significantly deeper (2-4 km compared to 0-2 km).

This event is the largest recorded at Lake Jocassee, the previous largest being M_L 3.2 on November 25, 1975. In search for a possible cause, we noted that the average lake level since March 1979 had been over 3 feet greater than in previous years and had been subject to rapid fluctuations in July and August 1979.

2. Monticello Reservoir

During this period we have acquired and analyzed data recorded on the Monticello reservoir network for a period August - December 4, 1978.

Results

The most significant event was a M_L 2.8 event on August 27, 1978 which was associated with a ground acceleration of 0.25g.

Precise hypocentral locations for this period indicate the activity can be divided into four clusters, and the fault plane solutions at each cluster reflect the local geology of the rock type(s) that the events are located on. We infer from this observation that the seismicity is associated with joint patterns which are different in different rocks (Figure 2).

3. Earthquake Prediction Studies

Lake Jocassee

There was a marked change in the pattern of seismicity at Lake Jocassee--the larger events do not appear to be associated with identifiable foreshock activity. The seismicity level has decreased markedly from what it was in late '75-early 1976, and is deeper. These observations suggest that the seismicity pattern has changed from Mogi type II to Mogi type I.

The August 26, 1979 earthquake was associated with a 3 day radon anomaly, the radon levels decreasing by 50% from the back ground two days before the event.

Monticello Reservoir

We have examined ts/tp ratio values for the events located near Monticello reservoir. Reliable ts/tp ratios were obtained from portable seismograph and magnetic tape playbacks. We have observed at least two periods of precursory decrease in ts/tp ratio values for $M_L \geq 2.0$ events on August 27 and September 15, 1978. The precursory time $\sim$ 15 days for these events is consistent with our observations at Lake Jocassee. The low ratio values up to 1.55 were associated with stations within about 5 km of the epicentral area while the distant stations were associated with normal ($\sim$ 1.75) ratio values suggesting that the affected region (dilatant zone?) is small--about 3 km in radius.

4. Velocity model for the Summerville-Charleston area

Using quarry blasts and those of our own making the velocity model for the Summerville-Charleston area was obtained. The model has been supplied to Charley Langer (USGS) for relocation of the S. C. seismicity.

Reports

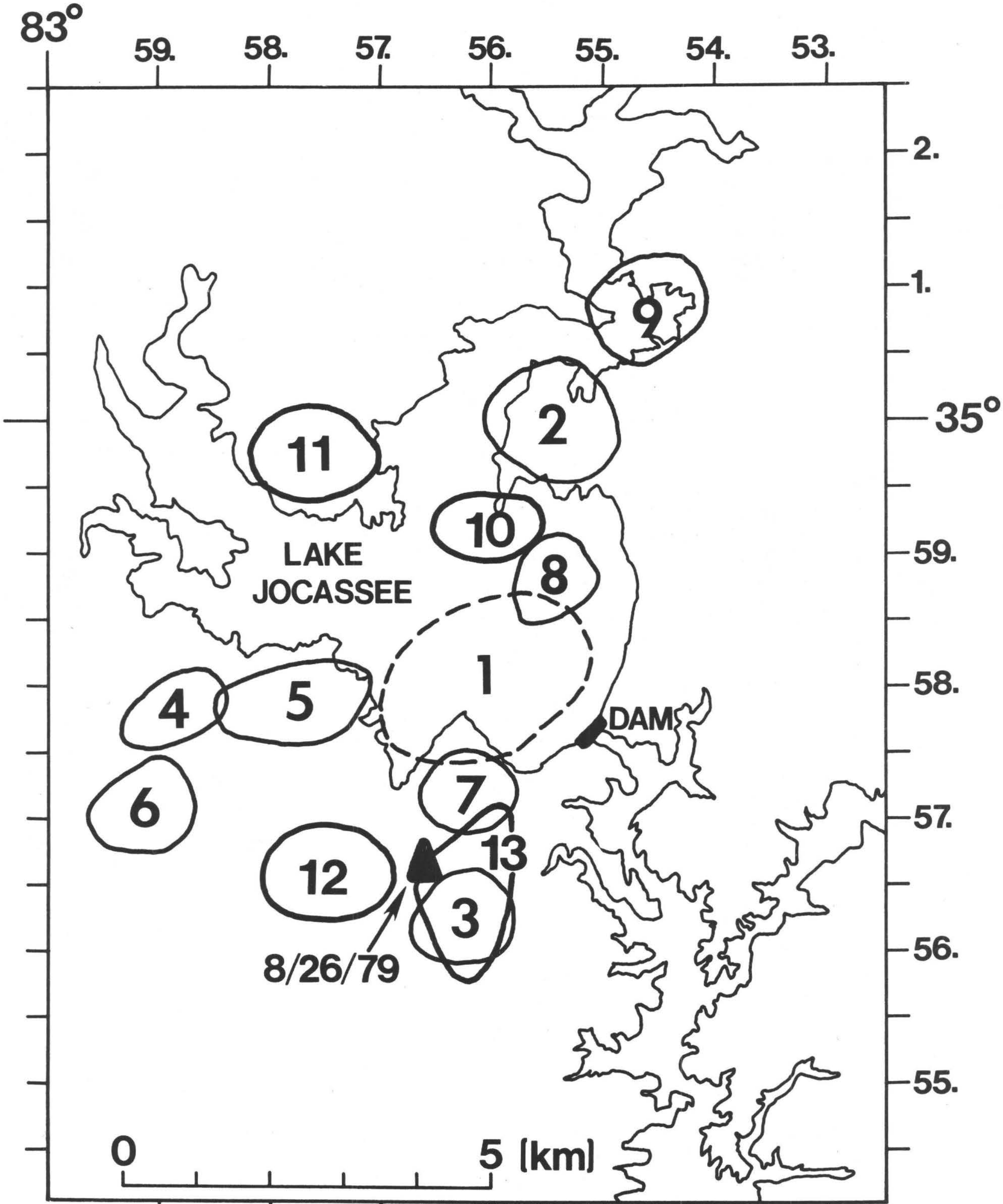
Talwani, P., Amick, D. C., Rastogi, B. K., and Duc, C., 1979. Induced seismicity studies at Monticello reservoir, South Carolina (Talk presented at 74th Annual Meeting of Seismological Society of America, Golden, Colorado) Earthquake Notes, V. 49, p. 58.

Talwani, P., and Rastogi, B. K., 1979. Mechanism for reservoir induced seismicity, Earthquake Notes, V. 49, p. 59.

Amick, D., and Talwani, P., 1979. An examination of Charleston-Summerville seismicity utilizing a new velocity model, Earthquake Notes, V. 49, p. 18-19.

Talwani, P., Amick, D. C., and Logan R., 1979. A model to explain the intraplate seismicity in the South Carolina Coastal Plain, EOS, V. 60, p. 311.

Rastogi, B. K., Talwani, P., Amick, D. C., and Duc, C., 1979. Ts/tp anomalies at Monticello reservoir, South Carolina, EOS, V. 60, p. 319.


83°
59.
58.
57.
56.
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54.
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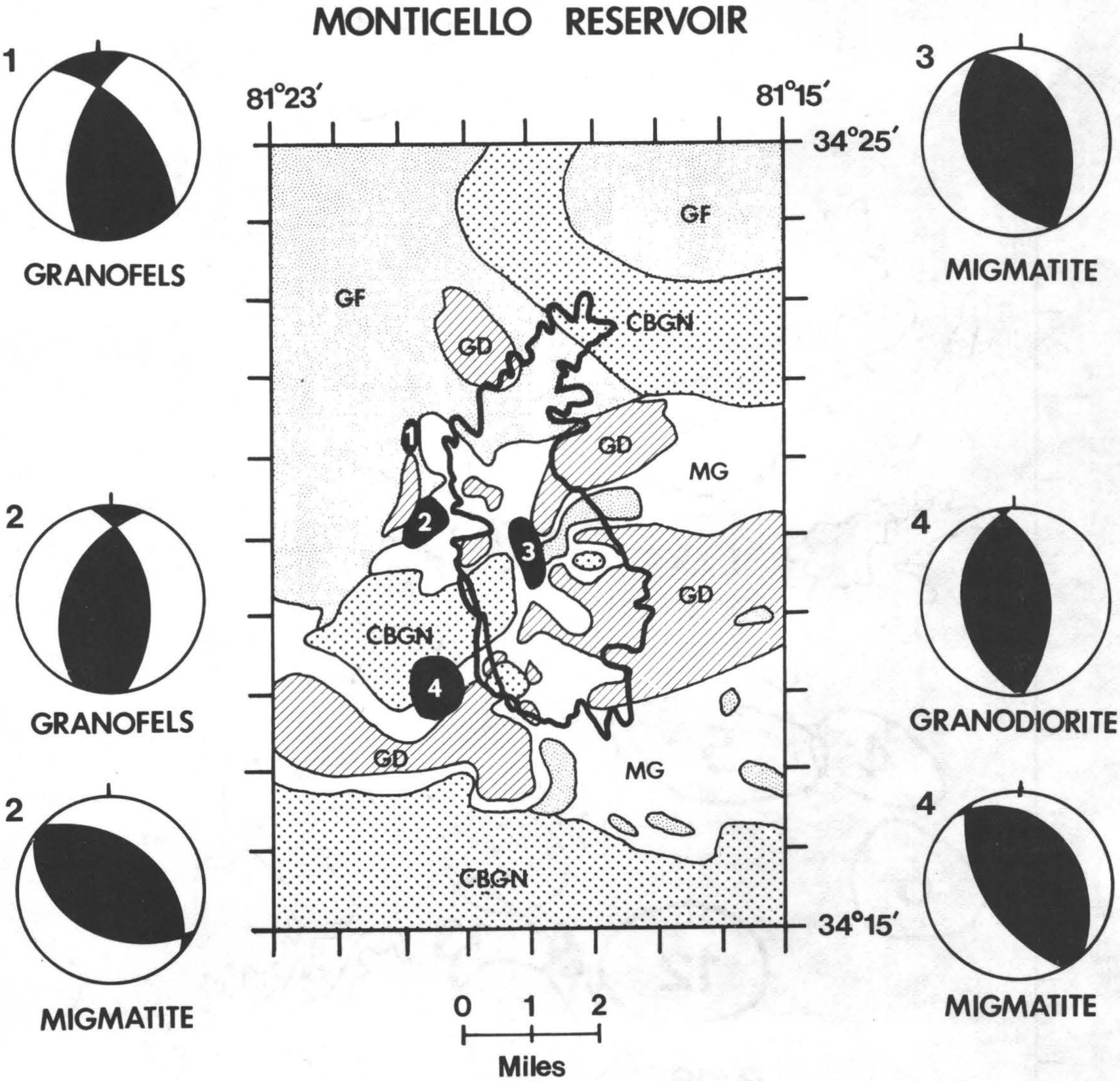
2.
1.
35°
59.
58.
57.
56.
55.
LAKE JOCASSEE
DAM
11
2
9
10
8
1
4
5
6
7
12
13
3
8/26/79
0
5 (km)

Figure 1



CBGN - Charlotte Belt Gneiss
GF - Granofels
MG - Migmatite
GD - Granodiorite

Crustal Structure Studies in the South Carolina Coastal Plain

Contract No. 14-08-0001-17670

Pradeep Talwani
Geology Department
University of South Carolina
Columbia, S. C. 29208
(803) 777-6449

CRUSTAL VELOCITY STRUCTURE IN CHARLESTON-SUMMERVILLE (S.C.) AREA

The results of over three summers of monitoring quarry blasts and blasts of our own making, have been combined into a M.S. thesis by David Amick. The emphasis has been on obtaining a velocity model in the epicentral area of the present day seismicity (also thought to be the location of the 1886 Charleston earthquake), in order to obtain better hypocentral locations.

LOCATIONS

The locations of five reversed profiles are shown in Figure 1; the astericks representing shot points, the encircled ones being quarries. The areas of local seismicity are around Summerville, and about 5 km NW of Bowman.

RESULTS

Travel time data from various shot points were inverted using constraints supplied by drilling (C.C. well, Figure 1) and short refraction profiles (Ackerman, 1977). The results are shown on a fence diagram (Figure 2). Three distinct velocity horizons are indicated, the shallowest of which is the surficial Cretaceous and post Cretaceous sediments (Vp 2.2 km/sec). The thickness of this unit varies from 0.54 km at GTQ to approximately 1 km at Papermaker and Medway. The base of this horizon appears to dip gently seaward. An intermediate horizon (Vp 4.75 km/sec) is present in the New Hope area at a depth of 0.65 km and extends 15 km northward to an apparent faulted boundary. This intermediate unit appears to thin to $\sim$ 500 meters near the Medway shot point and thins to the northeast, being absent in the GTQ area. Another possible intermediate horizon (Vp 5.5 km/sec) has a depth of 0.73 km and seems to be present over an area extending from just north of Papermaker for about 10 km toward New Hope. Its depth (0.73 km) is almost identical to the depth of the basalt observed in Clubhouse Crossroads well (0.75 km) and its velocity (5.5 km/sec) appears to be too low for crystalline basement, but can be explained by the 0.25 km thick basalt layer encountered in the CCC well. We interpret this horizon to be basalt.

The high velocity (Vp 6.0 km/sec) horizon present over the study area appears to represent the crystalline basement. Depths to this horizon vary from 0.54 km near GTQ to over 2.0 km at New Hope.

GENERALIZED VELOCITY MODEL

The travel time data were then combined to obtain the following generalized velocity model.

Vp (km/sec)	DEPTH TO TOP OF HORIZON (km)
2.20	0.00
5.98	1.18
8.15	29.91

From a knowledge of the local subsurface structure, station corrections were obtained for all permanent stations of the South Carolina seismographic networks (including the mininetworks). The blasts within the Charleston-Summerville area were relocated using the velocity model and the relocations were accurate to within 500 m. One blast lying 25 km from the nearest permanent station was relocated, and its computed epicenter was 5 km from the quarry. Thus the relocation accuracy of events outside the network is $\sim \pm$ 5 km.

RELOCATION OF COASTAL PLAIN EVENTS

Earthquakes occurring between 1974 - 1977 in the Summerville-Charleston area and near Bowman, were relocated. The newer epicenters were found to be diffuse and trending NW-SE in the Summerville area and NE-SW in Bowman area (Figure 3). A vertical cross section transverse to epicentral trend (Figure 4) and a composite fault plane solution (Figure 5) using the best recorded events suggests thrust faulting, striking NW on a plane dipping to the SW.

REPORTS

Amick, David and Pradeep Talwani, 1979, An Examination of Charleston - Summerville Seismicity Utilizing a New Velocity Model, Earthquake Notes, Vol. 49, No. 4, p. 18-19.

Talwani, P., D. C. Amick, B. K. Rastogi and C. Duc, 1979, Induced Seismicity Studies at Monticello Reservoir, South Carolina, Earthquake Notes, Vol. 49, No. 4, p. 58.

Talwani, Pradeep and B. K. Rastogi, 1979, Mechanism for Reservoir Induced Seismicity, Earthquake Notes, Vol. 49, No. 4, p. 59.

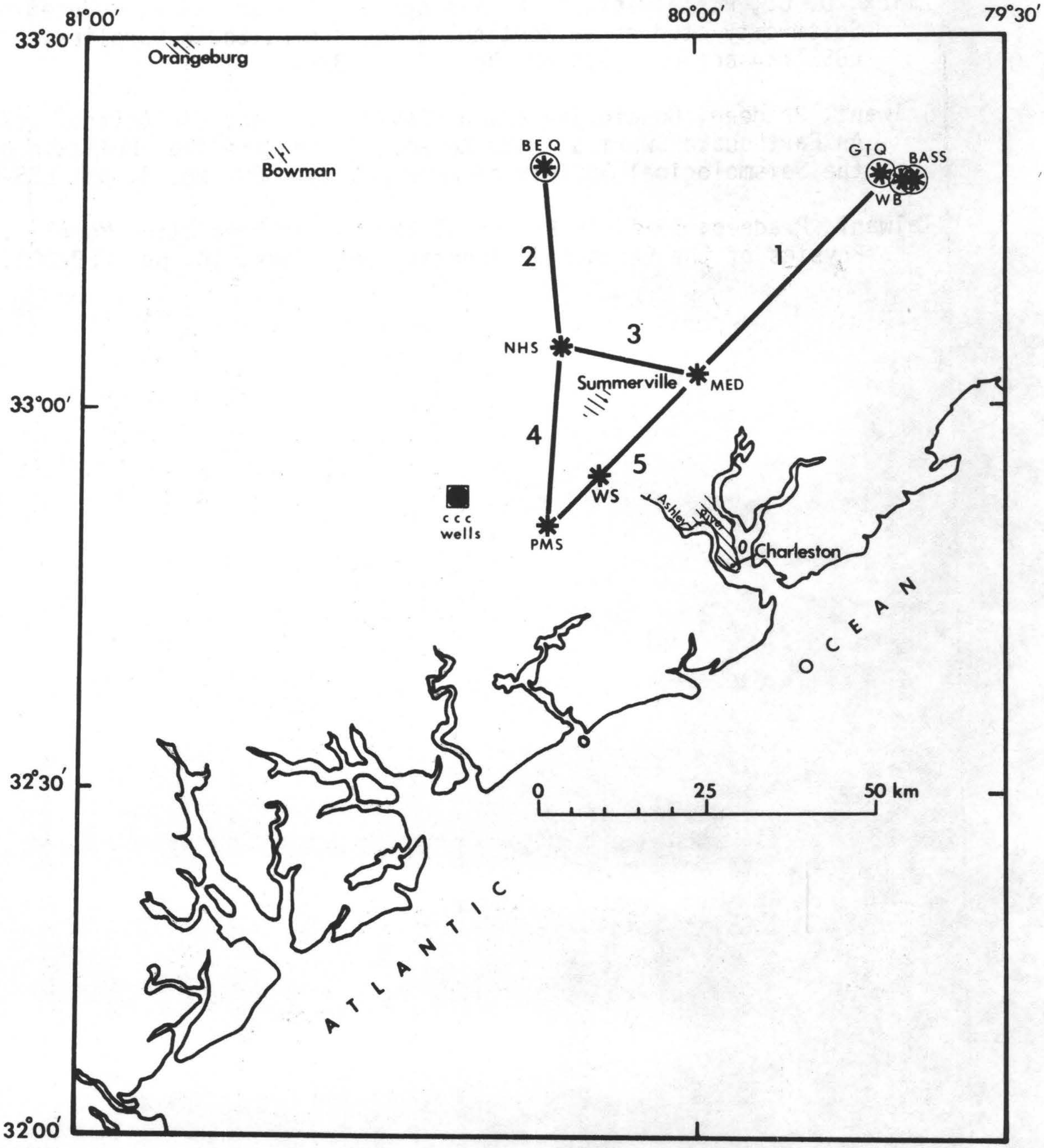
Talwani, Pradeep, A Model to Explain the Intraplate Seismicity in the South Carolina Coastal Plain, 1979, EOS Transactions, AGU 60, No. 18, p. 311.

Rastogi, B. K., P. Talwani, D. C. Amick and C. Duc, 1979, Ts/Tp Anomalies at Monticello Reservoir, South Carolina, EOS Transactions, AGU 60, No. 18, p. 319.

Amick, D. C., P. Talwani, B. K. Rastogi and C. Duc, 1979, Induced Seismicity studies at Monticello Reservoir, South Carolina, EOS Transactions, AGU 60, No. 18, p. 320.

Talwani, Pradeep, Donald Stevenson, David Amick and Jin Chiang, 1979, An Earthquake Swarm at Lake Keowee, South Carolina, Bulletin of the Seismological Society of America, Vol. 69, No. 3, pp. 825-841.

Talwani, Pradeep, 1979, An Empirical Earthquake Prediction Model, Physics of the Earth and Planetary Interiors, 18, pp. 288-302.


81°00′
80°00′
79°30′
33°30′
33°00′
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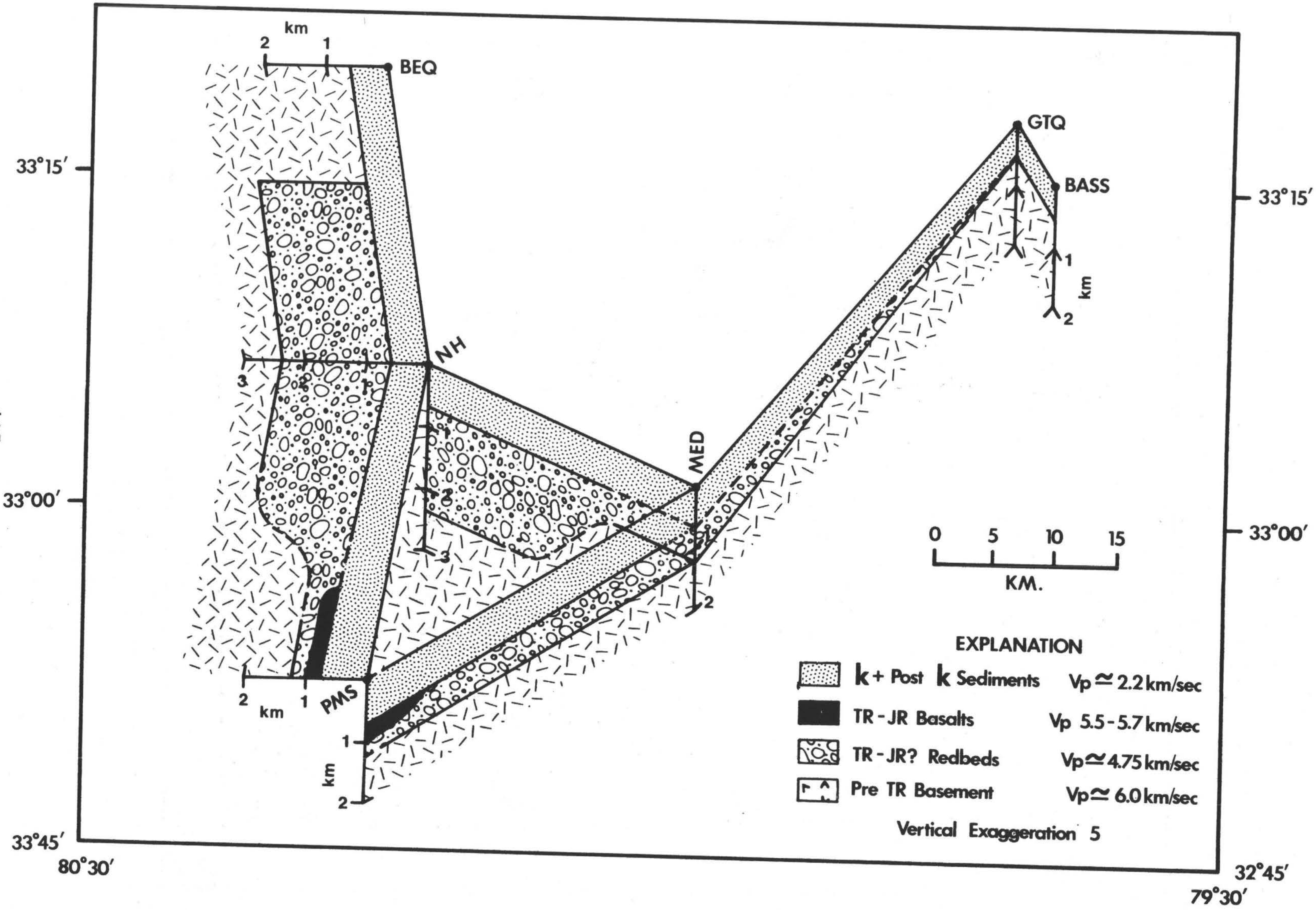
Orangeburg
Bowman
BEQ
GTQ
BASS
WB
1
2
3
4
5
NHS
Summerville
MED
WS
PMS
ccc wells
Ashley River
Charleston
0
25
50 km
ATLANTIC
OCEAN


BEQ
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80°30′
32°45′
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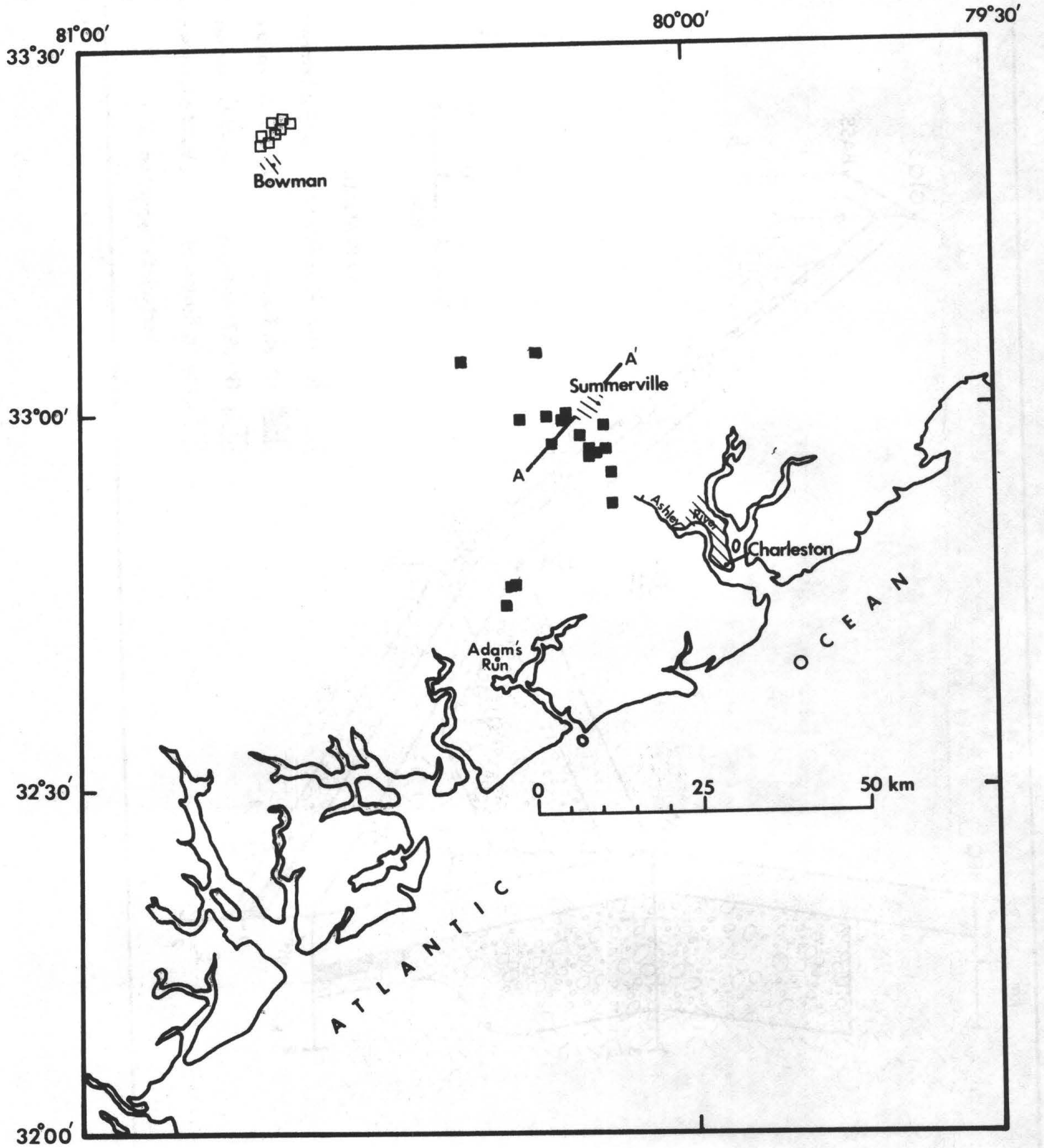
KM.
EXPLANATION
k + Post k Sediments Vp ≃ 2.2 km/sec
TR - JR Basalts Vp 5.5 - 5.7 km/sec
TR - JR? Redbeds Vp ≃ 4.75 km/sec
Pre TR Basement Vp ≃ 6.0 km/sec
Vertical Exaggeration 5

I.S.


81°00′
80°00′
79°30′
33°30′
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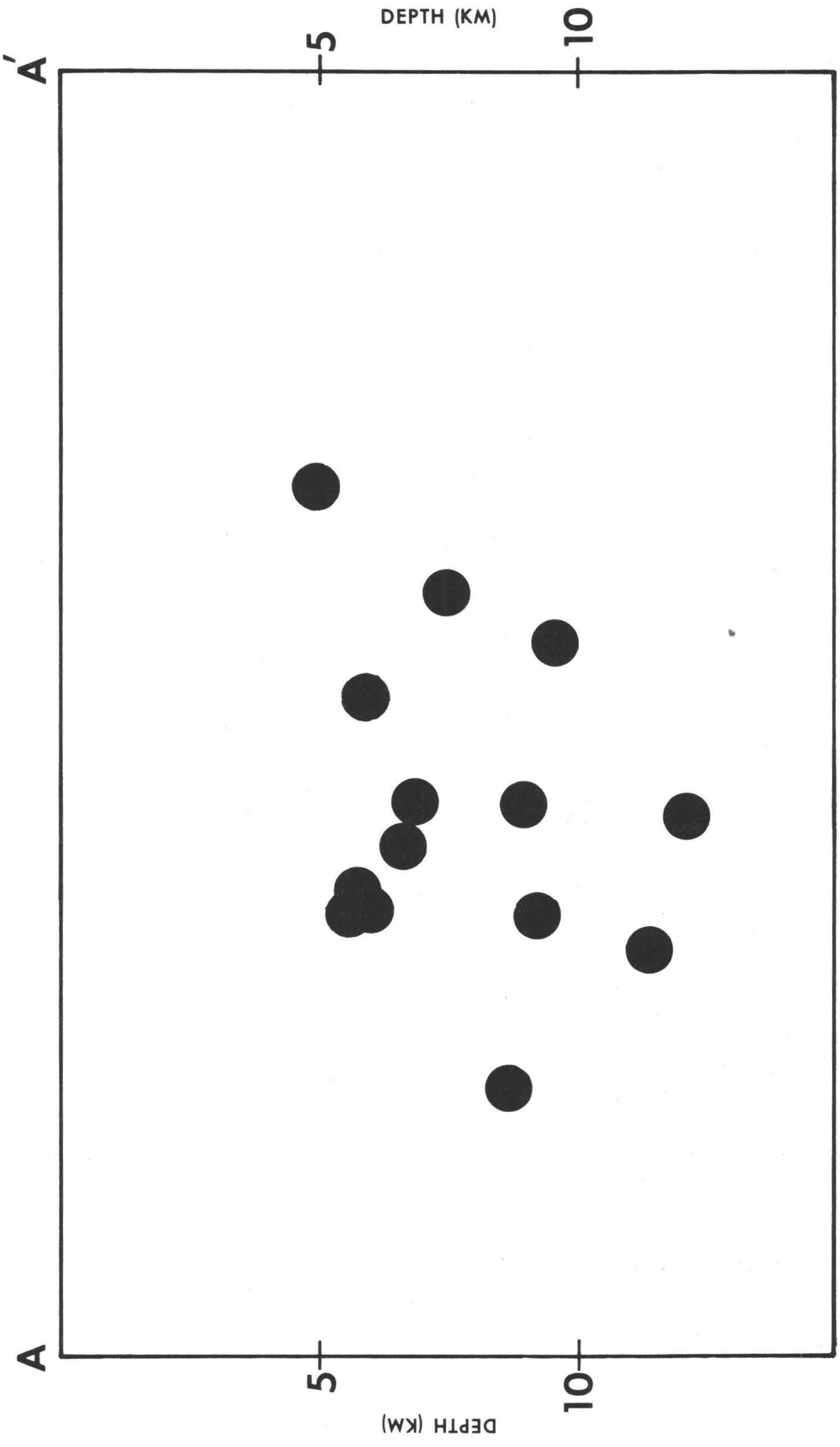
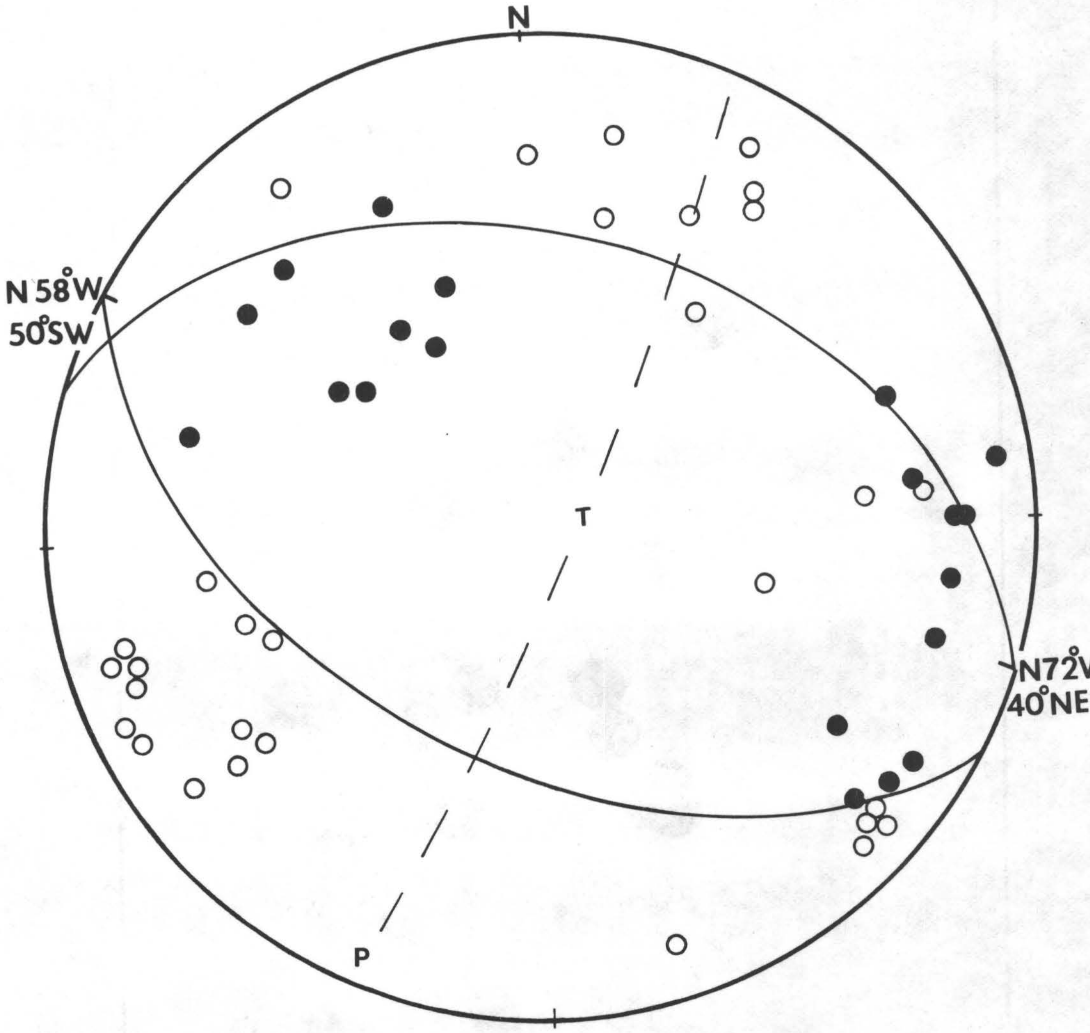
Bowman
A′
Summerville
A
Ashley River
Charleston
Adam's Run
0
25
50 km
ATLANTIC
OCEAN


A′
A
DEPTH (KM)
5
10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P

Project Title: Earthquake Hazard Studies in Northeastern United States

Contract Number: USGS-14-08-0001-17704

Principal Investigators: Y.P. Aggarwal, L.R. Sykes

Institution: Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York 10964

Telephone Number: 914-359-2900

Investigations

Local earthquake data recorded by a network of short period stations in northeastern United States and southern Quebec, Canada were analyzed to study the seismicity, the relationship of earthquakes to known faults, and the state of stress in this region. More than 25 focal mechanism solutions for earthquakes in this region were determined. The stress directions inferred from these solutions were compared to stress directions in other intraplate regions of the world to decipher the causal mechanisms of stress in these regions.

Results

i) Seismicity and Relationship of Earthquakes to Faults

Hypocentral locations for more than 400 local events ($1 \leq m_b \leq 5$) were determined. A comparison of the spatial distribution of these recent (1971-1979) events with historical earthquakes for the period 1534-1959 reveals that seismic processes in the northeast are relatively stationary: those areas of the northeast that have had little or no seismic activity historically are relatively aseismic today, whereas the historically active areas are also active today. Focal depth determinations indicate that earthquakes in this region are probably restricted to the upper and mid-crustal depths. The maximum focal depth varies spatially and appears to be related to lateral variations in crustal structure.

Hypocentral locations and focal mechanism solutions for earthquakes in southeastern New York, northern New Jersey and western New York indicate that earthquakes in these areas mostly occur along pre-existing faults. Focal mechanism solutions for earthquakes in coastal New England also suggest that these events are related to northeasterly trending faults in this region. In contrast, focal mechanism solutions for earthquakes in the Adirondack region suggest that these events are not related to pre-existing faults that predominantly trend northeasterly.

ii) State of Stress

The maximum horizontal compressive stress directions (σ_1) inferred from focal mechanism solutions delineate two distinct provinces in each of which the σ_1 axes are largely uniform. Earthquakes located in northern Virginia, New Jersey, southeastern New York and coastal New England generally show high angle reverse faulting with σ_1 trending E-SE. West of the Appalachians, in the Adirondacks, western Quebec and western New York, the σ_1 axis changes to ENE. In contrast, focal mechanism solution of an earthquake located offshore near Grand Banks shows normal faulting. Thus, it appears that the state of stress changes from an extentional regime offshore near the continental margin to compressional towards the interior of the continent.

In an attempt to decipher the likely causal mechanisms of stresses in this region and in the interior of other "non-subducting" plates we compared the stress directions in eastern North America with those in Arctic Canada, Indian Peninsula, western Europe, Antarctica and offshore Greenland. We find that in general that large areas outside the limits of continental margins are typified by horizontal compression. For these regions the σ_1 axes inferred from focal mechanism solutions or hydrofracture data show remarkable parallelism with the predicted orientation of horizontal compression arising from horizontal density variations in the upper mantle induced by the cooling of the oceanic lithosphere as it moves away from spreading centers. In contrast, both horizontal compression and extension are observed within the marginal areas. In the marginal area the state of stress appears to be influenced by sediment loading, density contrasts between oceanic and continental lithosphere, as well as the relative configuration of continental margins and spreading centers.

Four papers discussing these results are in preparation by Yang and Aggarwal.

Reports

Aggarwal, Y.P., and Yang, J.-P., 1978, Earthquake risk provinces in northeastern North America (abstract): Earthquake Notes, v. 49, no. 3, p. 8.

Aggarwal, Y.P., 1978, Intensity-magnitude relationship for eastern North America (abstract): Earthquake Notes, v. 49, no. 3, 8.

Golisano, M., 1979, Regional Seismicity Bulletin (1978) of the Lamont-Doherty Network: Lamont-Doherty Geological Observatory Publication.

Sykes, L.R., 1978, Intraplate seismicity, reactivation of preexisting zones of weakness, alkaline magmatism, and other tectonism postdating continental fragmentation: Review of Geophysics and Space Physics, v. 16, no. 4, 621-687.

Yang, J.-P., and Aggarwal, Y.P., 1979, Intraplate stresses: observations and causal mechanisms (abstract): submitted to AGU 1979 Fall Meeting.

Pennsylvania Seismic Monitoring Network (Northeastern United States Seismic Network)

14-08-0001-17634

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Investigations

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

Results

The first eleven stations of the network as shown in Figure 1 have been installed and are in routine operation with data transmission via telephone telemetry to the central recording site at Penn State's main campus. All eleven are at or near a college or university campus and visible recorders are (or will be) operated at each location by local faculty who have agreed to cooperate. Table 1 gives the locations of these stations and the local faculty contact. This strategy of monitoring provides backup analog recording and stimulates local public interest in the network operation. Stations 12 and 13 in Maryland and West Virginia, respectively, now operated by NASA, are being added to the network as telemetered stations. Each station consists nominally of a single, 1 Hz vertical seismometer (HS-10) with a VCO interface to telephone telemetry. In addition the stations indicated by asterisks in Table 1 have 3-component capability, including long period. The primary recording system is a develocorder film recorder, but simultaneous digital recording of up to 16 channels is possible with a NOVA 2 system at the central recording site at Penn State.

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

Two earthquakes were confirmed in Pennsylvania during 1978, one on July 16, 1978 (m_b=3) and the other on Ocotber 6, 1978 (m_b=3.1), both in Lancaster County, PA. Our approach of placing network stations at Pennsylvania college or university locations where there are geosciences faculty (see Table 1) is paying dividends in terms of geologic and tectonic interpretation. Prof. Charles Scharnberger at Millersville State College, the local station operator at that site, carried out the local intensity study of these events (Scharnberger; 1978a, 1978b). Figure 2 shows on a geologic map the epicenters inferred by the isoseismal data as compared to the instrumental locations. If the locations based on isoseismals are correct it is clear that both are in the vicinity of mapped faults with the October 6 event located at the intersection of several faults (see Figure 2). The shallow depths (about 5) inferred from the hypocenter determinations appear to be supported by the reports of sounds accompanying both earthquakes. (Coincidentally, for both events there were reports of unusual animal behavior a few minutes before the earthquake occurred.) With portable units we detected (at only one of two stations) what appear to be several small aftershocks of the July 16 event with magnitudes of approximatley 1.5 on July 18-19. Although we did not monitor the second event for aftershocks with portable gear, the Millersville station was close to the epicenter (approximatley 10 km) and no aftershocks were observed. It is clearly important to obtain the focal mechanisms for events in this area to determine which fault or fault system is active and to infer the orientation of the principal stresses in the crust.

Reports

Alexander, S.S., 1979, Seismic Monitoring to Learn More About Eastern U.S. Earthquakes, Earth and Mineral Sciences Bulletin, The Pennsylvania State University, V. 48, No. 6 (also in the Earthquake Engineering Research Institute Newsletter, Vol. 13, No. 3, 114-116, May 1979).

Baumgardt, D.B., S.S. Alexander and P. McHale, 1978, Relative Regional Event Location Using Combined Regional and Teleseismic Network Data, Earthquake Notes, Vol. 49, No. 3, pg. 10.

Scharnberger, C.K., 1978a, The Lancaster County Earthquake, Pennsylvania Geology, Pennsylvania Geological Survey, Vol. 9, No. 5, pp. 2-5.

Scharnberger, C.K., 1978b, Another Lancaster County Earthquake, Pennsylvania Geology, Pennsylvania Geological Survey, Vol. 9, No. 6, pp. 2-5.

Table 1

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

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

* Three-component stations

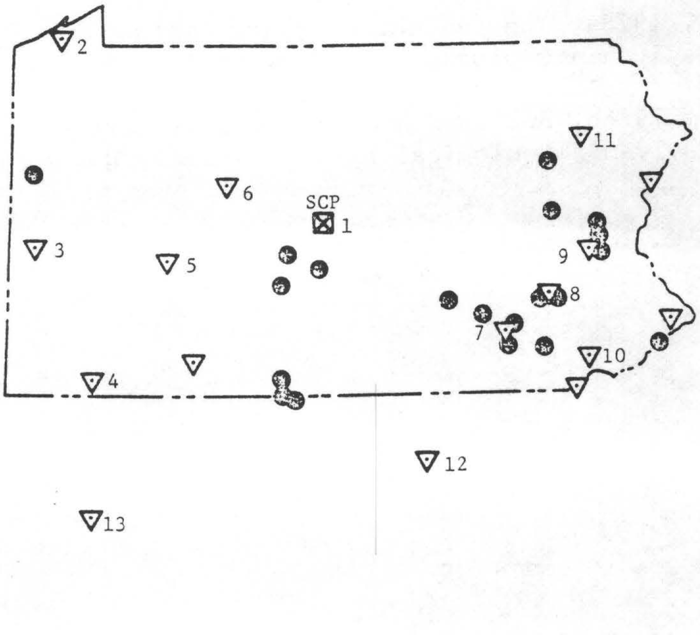

Figure 1. Map showing locations in the Pennsylvania Seismic Monitoring Network (triangles) and the eipcenters of previous earthquakes in the region (solid dots). Data from each network station is transmitted via telephone line to a central recording site at Penn State's main campus at State College,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

12

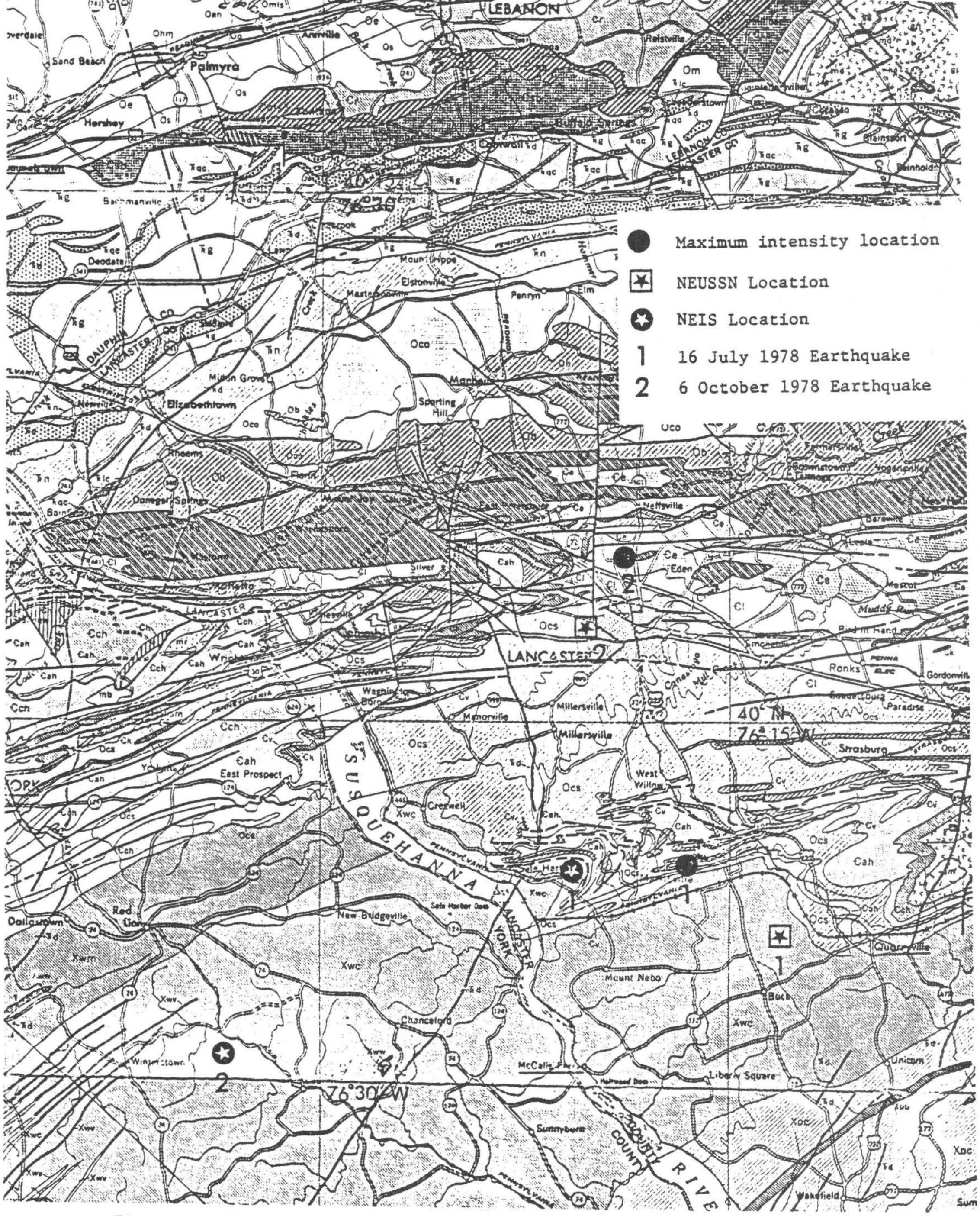

Figure 2. Comparison of locations from NEIS and NEUSSN networks with location from maximum intensity.

Southern California Seismic Arrays

Contract No. 14-08-0001-16719

Clarence R. Allen and James H. Whitcomb
Seismological Laboratory, California Institute of Technology
Pasadena, California 91125 (213-795-6811)

This semi-annual report covers the six-month period from 1 April 1979 to 30 September 1979. 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 own employees stations at Caltech. According to the contract, the primary visible product will be a joint Caltech-USGS catalog of earthquakes in the Southern California region, to be issued on a yearly basis, although quarterly epicenter maps and preliminary catalogs are also required. Figure 1 shows preliminary epicenters of all events that were detected and located by SCARLET during the six-month period.

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

Number of located events: 2,849
Number of earthquakes of M = 3.0 and above: 130
Number of earthquakes of M = 4.0 and above: 11, data for which were immediately transmitted by telephone to interested agencies, according to pre-arranged procedures.
Number of earthquakes reported to the Seismological Laboratory as having been felt: 35
Largest earthquake: M = 4.8 (6-30-79, near Big Bear Lake)
Smallest earthquake reported felt: M = 2.0 (8-6-79 0703 GMT, felt in Los Angeles, and 9-28-79, 2008 GMT, felt at CBS in Hollywood)

This was a period of more or less normal seismic activity in the Southern California region. The most significant sequences were a small swarm near Wiest Lake, in the Imperial Valley in June, during which 181 events were detected and located, and the Big Bear earthquake sequence which occurred in late June and early July. A number of events above magnitude 4.0 also took place in the Mammoth Lakes region in August and September. 795 aftershocks from the Homestead Valley earthquake of 15 March 1979 were recorded and located during this six-month period.

The Big Bear earthquake sequence consisted of a total of 30 detectable events, three of which exceeded magnitude 4.0. The situation of the center of activity within the densest part of the seismic network provided an opportunity to demonstrate the power of the network in relative locations of aftershocks for a fairly small event. Figure 2 shows a cross section of the spatial distribution of events. The shocks on 29 June, labeled "foreshocks" in Figure 2, had normal focal mechanisms. The others, the hypocenters of which define a different fault plane, exhibited strike-slip mechanisms. The line tracing the main fault plane in the Figure is 2 km in length.

The 1978 catalog epicenters were finalized during this reporting period. The final published catalog for that period should be forthcoming soon.

Caltech and USGS personnel continue to participate on a half-and-half basis in the CEDAR timing and location routine, alternating in two-hour shifts. The daily routine takes an average of 8-10 hours. Currently 146 seismic signals are being monitored by the CEDAR system.

Two new USGS seismic stations were added to the network processing load during this rpeorting period. Flash 2 (FLS), just north of Barstow, went on line 7 June 1979 and Joseph Francis Staten (JFS), on Government Peak near Roudsberg, California also went on line 7 June 1979.

PUBLICATIONS

Hutton, L. K., Allen, C. R., Blanchard, A. C., Fisher, S. A., German, P. T., Given, D. D., Johnson, C. E., Lamanuzzi, V. D., Reed, B. A., Richter, K. J., Whitcomb, J. H., 1979. Southern California Array for Research on Local Earthquakes and Teleseisms (SCARLET), Caltech-USGS Monthly Preliminary Epicenters for January 1979 through March 1979: Pasadena, California Institute of Technology.

Hutton, L. K., Allen, C. R., Blanchard, A. C., Fisher, S. A., German, P. T., Given, D. D., Johnson, C. E., Lamanuzzi, V. D., Reed, B. A., Richter, K. J., Whitcomb, J. H., Southern California Array for Research on Local Earthquakes and Teleseisms (SCARLET), Caltech-USGS Monthly Preliminary Epicenters for April 1979 through June 1979: Pasadena, California Institute of Technology.

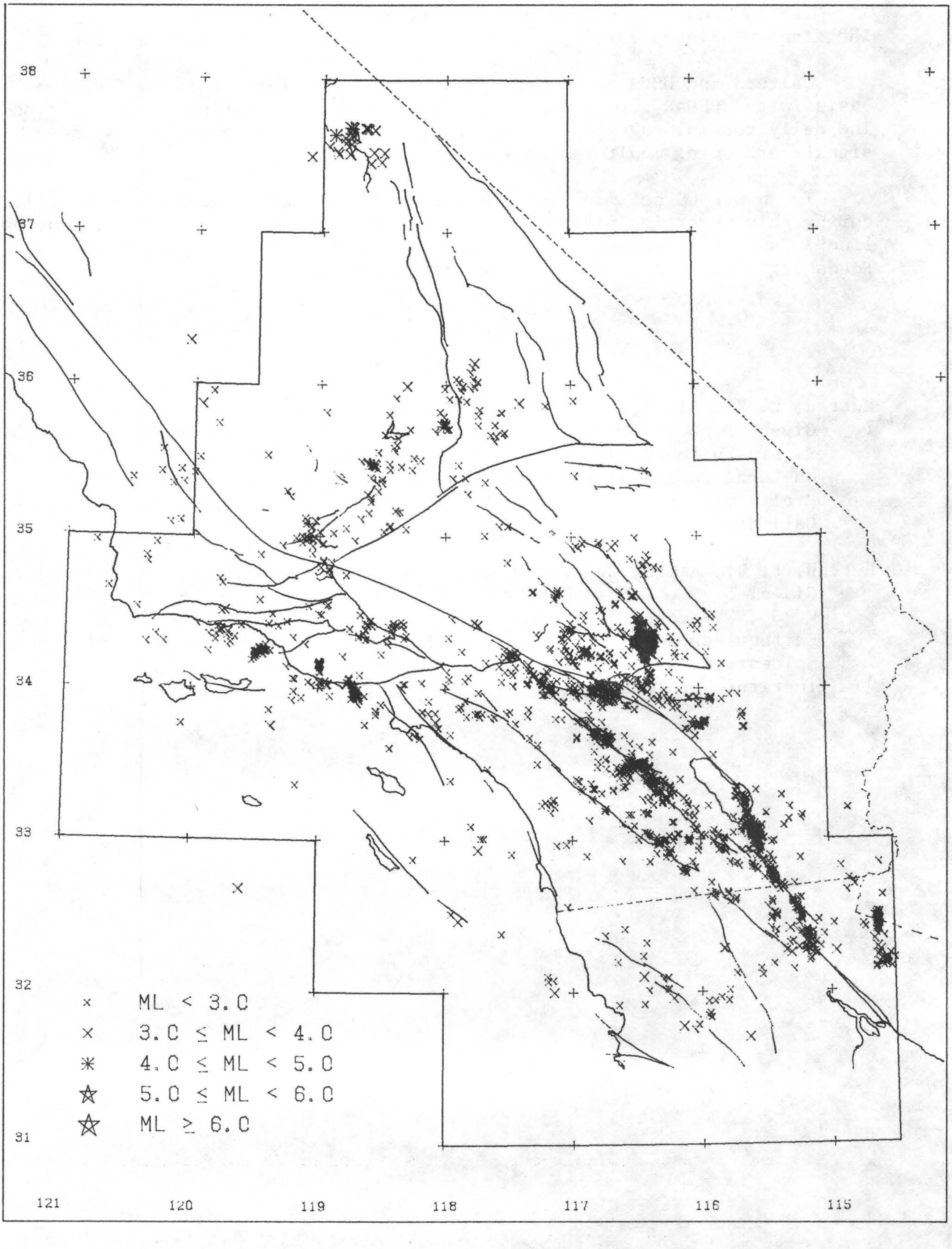

Figure 1. Epicenters of all earthquakes timed and located by SCARLET during the period 1 April 1979 through 30 September 1979.

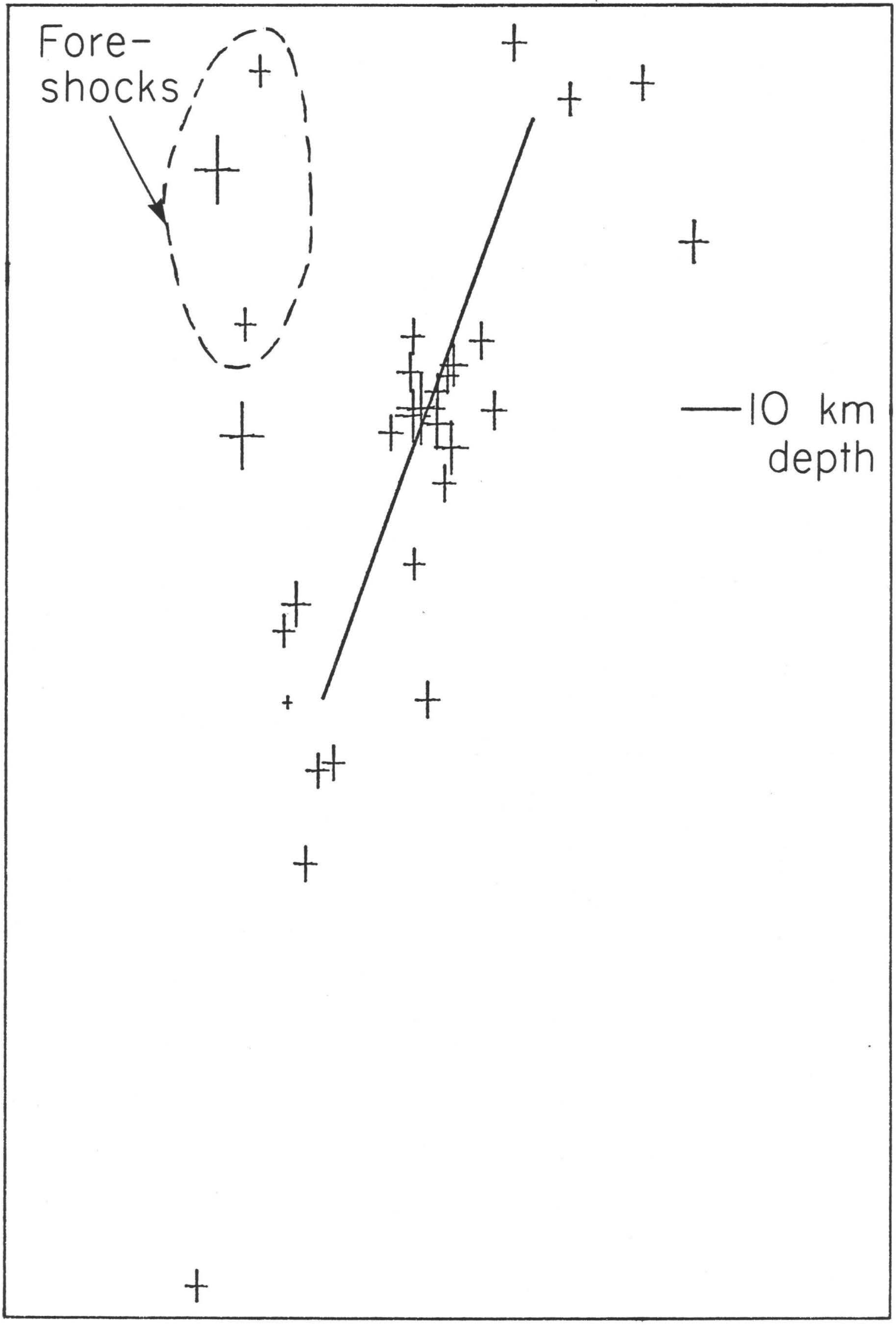

Figure 2. Cross section of the Big Bear earthquake sequence in late June and early July 1979. The line marking the inferred fault plane is 2 km in length.

Microprocessor-Based Seismic Processing

9970-02119

Rex Allen
Branch of Networks Operations
U.S. Geological Survey - MS-77
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Menlo Park, CA 94025
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Investigations

The earthquake picker algorithm developed earlier has been adapted for use in a multiprocessing environment in which each microprocessor monitors eight seismic lines. Up to 32 processors (256 seismic lines) report to another microprocessor which acts as a supervisor for the pickers. This supervisor accepts reports of probable seismic events, cross-references them, and sorts out which reports should be grouped together as representing one earthquake. In performing this task the supervisor makes use of station location information and calculates a preliminary location for the event. Output from the supervisor consists of station arrival information in standard phase card format for use by any of the usual USGS locator programs such as HYPOINVERSE or HYPO71. Output is via a RS-232 link which can go to a recording device such as a card punch or line printer; or it may go directly to a computer for on-line location.

Results

The 80-input prototype is in operation with results being reported to the PDP 11/70 for locating through HYPO71. The southern portion of the Central California Net is being monitored and results compared with hand picks. Preliminary evaluations indicate the automatic system will be comparable with handpicks made from film, but not as good as those from paper playbacks.

Very Long Period Seismic Studies in the U.S.S.R.

USDIGS 51622

Jonathan Berger and Freeman Gilbert

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University of California, San Diego
La Jolla, California 92093

(714) 452-2889

Two Project IDA long period seismic stations have been established in the USSR, one in Garm, Tadzhikistan and the other at Sakhalin Island, in the Soviet far east. During the contract period, the instruments in Garm were moved from a noisy riverside vault to a hillside tunnel which has proved to be very quiet seismically.

SUMMARY REPORT

COOPERATIVE U.S.-MEXICO SEISMIC HAZARD AND EARTHQUAKE PREDICTION STUDIES IN NORTHWEST MEXICO

USGS USDI-14-08-0001-16896

by

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Research under this contract has covered three separate areas: First, design and construction of a digital telemetering array of seismic stations for Northern Baja California; second, studies of the historical and current seismicity of that region, and third, special studies undertaken following the 29 November, 1978 and 14 March, 1979 Mexican earthquakes. All of the above work is being conducted with the scientists and staff of the Center for Scientific Investigation and Higher Education of Ensenada, Baja California (CICESE). This research is continuing under U.S.G.S. Contract USDI-14-08-0001-18216.

I. Northern Baja California Seismic Array.

Although this contract for the design, construction and installation of the array has terminated, the array is still in the construction stages. The use of microwave links for data transmission between the Mexicali Valley and Ensenada was found to be extremely noisy and unreliable. A radio (VHF and UHF) telemetry system, which has been tested over short ranges in the vicinity of Ensenada, has been designed. The system consists of VHF radio links between each station and San Pedro Martir peak, where the data will be multiplexed and transmitted on UHF to Ensenada. All components for this system have been purchased, but many long lead-time items have not yet arrived.

As discussed in previous reports, the field work and data analysis following the Oaxaca earthquake caused a delay of several months in the design and testing of the digital telemetry system. We presently anticipate that station installation will begin in late summer.

So that some data on regional seismicity can be obtained before array installation, we have installed three temporary stations in Northern Baja California to complement existing analog stations. Two event-triggered digital recorders (Terra Tech DCS 302) and one analog drum recorder are operating at sites shown in Figure 1. Although these stations lie along a line, epicentral calculations will be made using those existing stations at Ensenada, Rio Hardy, Qukapah and other stations of the Cerro Prieto and Southern California networks.

Data from these temporary stations will allow more accurate epicentral locations of events along the San Miguel Fault zone than previously available. Also, the two digital stations (3 components) will provide the opportunity to examine spectral characteristics of the recorded waveforms for studies of regional variations in stress drops and attenuation. One purpose of the digital array will be to examine temporal variations in these parameters, among others, to see how the stress field might change before larger earthquakes. These temporary stations can provide some important initial data.

II. Studies of Historical and Recent Northern Baja California Seismicity.

Several special studies of historical Baja California seismicity have been undertaken in an effort to understand the seismicity patterns in this complex region.

Alena Leeds recently completed a masters' thesis on the relocation of larger events which occurred in Northern Baja California before 1964. Of the ten M > 5 events she relocated, five appear to have occurred along the San Miguel Fault zone, including those of the 1954 sequence, previously attributed to the Agua Blanca Fault. One more could have occurred on the southern portion of the San Miguel, or on another of the many faults which apparently intersect southeast of Ensenada. Leeds' locations are shown in Figure 2. A more complete description of the study is being prepared for publication.

A large earthquake swarm occurred in the Sierra Juarez - Laguna Salada area beginning in December, 1975 and continuing through most of 1976. The swarm contained seven events with $M_L \geq 4$, five of which occurred during January 1976. Cal Tech has located several hundred swarm events, but the epicenters show considerable scatter. In an attempt to reduce that scatter, arrival times of events recorded at Rio Hardy (RHM) and Ensenada (ENS) are being read and will be included in a relocation of the swarm. The relocations, along with body and surface wave anlayses, will help determine the mechanism of the swarm, and its place in the region's seismic history. This latter point is very important, since the swarm did not occur near a known spreading center or even along the main San Andreas - Imperial - Cerro Prieto fault system.

III. Oaxaca and Guerrero, Mexico, Earthquakes.

UCSD and CICESE carried out an extensive field program following the 29 November, 1978, Oaxaca earthquake. Both smoked paper and digital recorders were deployed in the aftershock zone of the $M_S \sim 7.8$ event. Recording continued over a period of four months. Aftershocks are being located at CICESE. L. Munguia has been analyzing some of the digital data. Twenty six aftershocks, with seismic moments from 1 to 164×10^{21} dyne-cm, had stress drops between 6 and 400 bars, with the deeper, onshore events tending to have higher stress drops. Preliminary results of our Oaxaca studies were presented at the Annual Meeting of the SSA in Golden, Colorado. Analyses of this extensive data set is continuing.

Following the 14 March, 1979 $M_S = 7.6$ earthquake near Petatlan, Guerrero, Mexico, portable field equipment was taken to the aftershock zone. Only smoked-paper recorders were installed in the field. In a ten day period, several hundred aftershocks were recorded by an array of six instruments. This data is presently being read, and events located by CICESE.

IV. CONCLUSIONS

Although these last two studies do not strictly pertain to our research in Northwest Mexico, they were added to our research effort because of their importance to our understanding of large earthquakes. The field work associated with those two events has delayed somewhat the installation of the permanent, digital telemetering array in Northern Baja California. Three temporary stations, with the help of existing analog stations, allow us to begin collecting data before the installation of the permanent network late this summer. The task of anlayzing the data will begin under our present contract (USGS USDI-14-08-0001-18216).

NATIONAL DIGITAL SEISMOGRAPH NETWORK (NDSN)

9920-02497

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Investigations

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

In an agreement with Bob Page, the Earthquake Hazards Program will fund the installation of five DWSSN digital recorders at College, Longmire, State College, French Village and Jamestown.

The installation at Jamestown, California, will be different in that there is no WWSSN system at the site but new sensors and associated equipment will be provided to give the correct parameters. Furthermore the digital data are to be telemetered from Jamestown to Berkeley and portions of the data in analog form from Berkeley to Menlo Park. The French Village will also entail telemetering the data to St. Louis. All the hardware equipment, including the telemetry components for the Jamestown station, and the digital recording system for French Village have been purchased. The equipment for the other three sites has been purchased with ARPA funds and is being assembled and tested at ASC.

Goals

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

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

Earthquake Hazard Studies in the Pacific Northwest

14-08-0001-16723

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April 1979

Investigations

1. Operation of the western Washington regional seismograph network.

2. Routine analysis and reporting of data from the western Washington regional seismograph network.

3. Study of focal mechanisms of local and regional earthquakes in western Washington.

4. Review of data from Puget Sound earthquake of March 11, 1979.

5. Investigation of crustal velocity structure of western Washington.

6. General study of tectonics of Pacific Northwest and relationship to earthquake hazards.

7. Conversion of network data acquisiton to fully digital system.

Results

1. Network operation continued during the report period with no major problems or disruptions. Work proceeded on several hardware improvements, including subcarrier frequency stabilization. Initial installation and testing of the digital data acquisition and processing system was completed.

2. Preliminary analysis of 1978 network data was completed and final editing of these data and preparation of a 1978 summary is proceeding. All data on western Washington earthquakes are now published through 1977 by the Division of Geology and Earth Resources, Olympia, Washington. In addition, a first quarter 1979 preliminary hypocenter summary is included as an appendix to this full report.

3. Careful examination of events recorded from the southern

part of the network for 1978 revealed that the preliminary catalog was contaminated by a large number of explosions. This discovery indicates that reassessment of older data for this region needs to be done and perhaps previous indications of the number of earthquakes in this area will be revised.

4. A current study of regional focal mechanisms is not yet complete. However, preliminary results show a general consistency with previous results for shallow earthquakes (less than 25 km depth). Earthquakes deeper than 35 to 40 km in the Puget Sound region however show a marked departure from the characteristics of the shallower events, indicating a different stress regime at depth.

5. Improvement in knowledge of the velocity structure below Puget Sound is being sought to improve hypocenter locations and also to better our understanding of the tectonic framework of the region. Several methods of improving the inversion of earthquake arrival times for hypocenter and structure are being tested and implemented.

6. The principal results of tectonic investigations indicate that there are two seismic zones beneath western Washington. A deep zone beginning at 35 to 40 km depth which may be subduction related, and a shallow zone above approximately 25 km which has characteristics unlike the deep zone. Based on existing data, the deep zone appears to be the source of major earthquakes in the greater Puget Sound region.

Reports

Crosson, R. S., and L. J. Noson, 1979, Compilation of earthquake hypocenters in western Washington - 1977, State of Washington Department of Natural Resources, Geology and Earth Resources Division, Inf. Circ. 66.

Earthquake Hazard Studies in the Pacific Northwest

14-08-0001-16723

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October 1979

Investigations

1. Operation of the western Washington regional seismograph network. 2. Analysis, compilation and reporting of regional hypocenter data. 3. Study of magnitude 4.6 southern Puget Sound earthquake of March 11, 1979. 4. Study of regional tectonics framework. 5. Investigation of crustal velocity structure of western Wasington. 6. Implementation of network digital data acquisition.

Results

1. Network operation continued with a stable configuration during the report period. Several changes were made to improve network operation, including: a) moving of station FTW to a nearby site, now designated MOW, b) moving of seismometer installation at station BFW for reduced background noise, c) preparation for installation of new station on the east side of the Olympic Mts. to improve coverage in that region.

2. A summary report was prepared for the year 1978, listing and plotting 367 well located earthquakes. We also included an update of network operation and data analysis procedures.

3. We have been able to obtain a main shock focal mechanism and focal mechanisms for several subsidiary earthquakes related to the magnitude 4.6 earthquake of March 11, 1978. The focal mechanisms indicate strike slip motion on a well constrained plane which strikes approximately N20W. Aftershocks align on a plane which strikes approximately N45W, clustering about the main shock hypocenter at a depth of 24 km. The apparent discrepancy may be due to structural distortion of the locations and possibly structural influence on the focal sphere projections. The area of the aftershock zone is approximately 10 square km and it is defined by about 50 well located events. The inferred rupture surface for this earthquake aligns with no known surface structures although its orientation generally tends to confirm previous conclusions regarding the principal stress directions in the crust above 30 km depth. This earthquake is the first well documented main shock aftershock

sequence in the central Puget Sound region.

4. A review and attempted synthesis of the regional tectonics from nearly a decade of detailed network observations is presently being undertaken. A most striking, and important, result is the existence of a deep zone of earthquakes which lies approximately on a plane striking N30W and dipping 15 degrees NE. The behavior of earthquakes in this zone is distinctly different from that of earthquakes in the shallower region above about 30 km depth. A seismically quiet interval between about 30 and 45 km depths suggests low strength. Structurally there is evidence that a low velocity layer also exists in this depth range. The deep and shallow zones of earthquakes have been compared on the basis of b-values, total energy release, and focal mechanisms. We hypothesize that most, if not all, of the major central Puget Sound earthquakes occur in the deep zone. The dip to the northeast suggests a relationship to subduction of the adjacent Juan de Fuca plate, but the details remain unclear.

5. Development is continuing on a method of efficiently approximating travel times in a laterally heterogeneous local earth model. Extensive testing of a computer algorithm has been completed and work to utilize this algorithm in inversion is continuing. Eventually, improvement in our knowledge of the local crust and upper mantle structure is sought.

6. Work is continuing in development of fully computerized data acquisition for the Washington networks. All hardware is installed and operational. Software development, involving several institutions, is continuing.

<u>Reports</u>

Crosson, R. S., and L. J. Noson, 1979, Compilation of earthquake hypocenters in western Washington - 1977, State of Washington, Department of Natural Resources, Geology and Earth Resources Division, Inf. Circ. 66.

Noson, L.J., and R.S. Crosson, 1979, Compilation of earthquake hypocenters in western Washington - 1978, prepared for submission to State of Washington, Department of Natural Resources, Geology and Earth Resources Division.

Reanalysis of Instrumentally-Recorded U. S. Earthquakes

9920-01901

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Investigations

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

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

Results

These results cover the researches of J. Dewey and D. Gordon on U. S. seismicity east of 85°W and the research of W. Gawthrop on the seismicity of the Nevada Seismic Zone.

(1) We have to date relocated 147 hypocenters of seismic events that occurred in the eastern United States and adjacent Canada in the interval 1924-1976. 44% of these shocks have "90% confidence ellipses" on their epicentral coordinates that are less than 10 km in length, and 76% have 90% confidence ellipses on their epicentral coordinates that are less than 20 km in length. Based on 23 seismic events whose locations are known independently of the travel-time data, it appears that there is some location error not accounted for by the confidence ellipses. Only 70% of the nominally 90% confidence ellipses cover the independently known epicenters of the 23 events. For some regions there is apparently location bias of about 5 km due to lateral variations of velocity that are not accounted for in the location procedure.

(2) The use of subsidiary phases and regional velocity models enables a significant improvement in accuracy of computed focal depths over those of the previous routinely-determined epicenters. Most computed hypocenters lie in the uppermost 10 km of the earth's crust. Excluding earthquakes from the province of Quebec and considering only the 71 earthquakes whose focal depths are estimated to be accurate to 20 km at a 90% lever of confidence, we find that 86% of these earthquakes occurred in the upper 10 km of the earth's crust. Among 12 Quebec earthquakes whose focal depths are estimated to be accurate to 20 km at a 90% level of confidence, however, we find that half of them occurred in the depth range 10 to 20 km.

(3) In our study of the seismicity of the Nevada Seismic Zone from 1932, we have compiled data and computed provisional epicenters for nearly 400 shocks that occurred during the years 1943-1974. Many of these shocks were associated with the Fallon-Stillwater, Fairview Peak-Dixie Valley, earthquakes of 1954. A summary of this sequence of earthquakes is as follows: (1) The strong earthquakes of July 6 and August 23, 1954, occurred west of the Stillwater Range. Faulting associated with the August 23 earthquake formed a northern extension of faulting associated with the July 6 earthquake. Both earthquakes had regionally-recorded aftershocks occurring near their respective fault scarps. (2) The Fairview Peak-Dixie Valley earthquakes of December 16, 1954, occurred 30-40 km east of the Fallon-Stillwater earthquakes and were associated with surface fault scarps that paralleled those of the Fallon-Stillwater earthquakes. The Fairview Peak-Dixie Valley faults extended approximately from 39.0°N to 39.8°N. The region of surface faulting from 39.0°N to about 39.6°N was associated with extensive aftershock activity, but the northernmost 30 km of the zone of surface faulting (including most of the Dixie Valley Fault) had no regionally-recorded aftershock activity on it. We have not yet relocated the Dixie Valley mainshock (which presents special problems because it occured only 4 minutes after the Fairview Peak mainshock), but the lack of aftershocks on most of the Dixie Valley fault supports hypotheses that some of the Dixie Valley fault traces may be secondary features rather than surface outcrops of the mainshock fault surface.

Central California Network Processing

9930-01160

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Investigations

Recordings from 250 stations of the multipurpose central California Seismic Network are Telemetered continuously to the central laboratory facility in Menlo Park where they are recorded, reduced, and analyzed to determine the origin times, magnitudes, and hypocenters of the earthquakes that occur in or near the network. Data on these events are presented in the form of lists, computer card catalogs, computer tape and mass data files, maps, and cross sections to summarize the seismic history of the region and to provide the basic data for further research in seismicity, earthquake hazards, and earthquake mechanics and prediction. A magnetic tape library of "dubbed" unprocessed records of the network for significant local earthquakes and teleseism is prepared to facilitate further detailed studies of crust and upper mantle structure and physical properties and of the mechanics of earthquake sources.

Results

Summary catalogs of earthquakes located by the network from 1969 through 1976 have been published. Preliminary results for the years 1977 through 1979 are accessible in various unpublished forms, and work on completing and publishing the summary catalogs for these years have high priority.

Pn velocities beneath the central California network have been studied by a modified time-term method applied to network recordings of many moderate (M=4+) local earthquakes. There is a velocity contrast of about 0.15 km/sec across a line that follows the San Andreas fault south of Hollister and the Calaveras, Hayward, Healdsburg, and Maacama faults north of Hollister. The Pn velocity averages about 8.10 km/sec west of this line and 7.95 km/sec east of this line. Pn time-terms increase systematically by about 1 sec across the Coast Ranges from the coastline to the western edge of the Great Valley.

California Seismic Network Development

9970-90007

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Investigations

Extend the central and southern California seismic networks to provide more uniform moderate density coverage of the San Andreas fault system and contiguous seismically active regions of California. In central California an additional 100 stations are needed, about half to broaden the southern part of the net and extend it to the Transverse Ranges and about half to extend the northern part of the network to the Klamath Mountains. In southern California an additional 75 stations are needed to provide moderate density coverage of the Transverse Ranges and of parts of the San Jacinto and San Andreas faults near Salton Sea and to provide selective augmentation of the network in the northern Mojave Desert and along the eastern flank of the Sierra Nevada.

Results

Tentative sites have been selected for the new stations, and priorities have been set up for their installation. Purchase and/or fabrication of equipment for two-thirds of the stations is nearly complete, and recording facilities (analog magnetic tape) have been established for the projected new stations.

Equipment has been installed in about 40 stations and work is underway on obtaining site use permits for an additional 20 stations in northern California.

During the next six months, emphasis will shift to southern California, where work on obtaining site use permits for the first few dozen new stations is underway.

Central California Network Operations

9970-01891

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Investigations

Maintenance and recording of 331 seismic, 34 tiltmeters, 16 magnetometers and 3 strainmeter locations in central and northern California covering 63,000 square miles.

Results

1. The Stanwick Corporation under contract 14-08-0001-16637 is responsible for the maintenance of approximately 350 seismic, tiltmeter, magnetometer and strainmeter field sites, inside maintenance of low frequency digital equipment, turnaround maintenance of most field equipment, and special fabrication and repair work designated by USGS.

2. The Stanwick team consisting of nine members has far exceeded maintenance goals set by the reference contract (95% operational). Maintenance delays greater than 48 hours were attributable to weather, transportation, or access problems to private land.

3. No traffic violations and one accident caused by weather in 260,000 miles of highway and off-road driving (3-year period).

4. New Seismic stations:

   Installation of:
   - 4 Multicomponent seismic stations in Livermore
   - 15 Single-component stations in Mendocino County
   - 8 Single component stations in Parkfield area
   - 4 Single component stations / Walker Pass
   - 3 Single component stations / Mt. Hamilton
   - 1 Single component station / Point Reyes

Enhancement of Data Acquisition in the New Madrid Seismic Zone

14-08-0001-16794

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January 1, 1979 - June 30, 1979

Goals

Augment monitoring of earthquakes in New Madrid Seismic Zone by the addition of sixteen new seismograph stations.

Install three three-component digital accelerographs to obtain strong motion records for small events in the zone of major seismicity.

Investigations

The present effort involves only an augmentation of equipment. Research studies utilizing the data acquired will be performed under Contract No. 14-08-0001-16708, "Earthquake Hazard Studies in Southeast Missouri."

Results

The digital accelerograph design is complete. The instruments are designed so that $\pm$ 0.25 g corresponds to $\pm$ 2048 counts. Usable data should be obtained for earthquake peak accelerations of $\pm$ 0.0025 g. The instruments are undergoing final testing prior to installation.

SEISMICITY OF THE RIO GRANDE RIFT

9920-01774

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Investigations and Results

Our investigation into the series of microearthquakes near the Albuquerque volcanoes has been completed. Our results are:

1. The earthquakes originated from a small (approximately two km. long by one km. wide by three km. deep) source.

2. A composite fault plane solution suggests that the activity is along a down to the west, high angle, normal fault.

3. The surface projection of this fault is in good agreement with the strike and geographic position of the fissures through which the volcanoes erupted.

4. The early part of the sequence was an earthquake swarm (approximately 100 events in four days). The subsequent activity suggests a foresbolic main shock (Mc=2.5), aftershock series.

5. An analysis of the delay times of local explosions suggests that the sedimentary section is near five km. thick at the volcanoes.

A project to study the seismicity and crustal structure of the San Juan Basin in Northwestern New Mexico is being implemented under USGS Uranium and Thorium Funding. The Field Reconnaissance, equipment procurement, and systems fabrication are complete. Five semi-permanent seismic monitoring sites have been permitted. All seismic data will be transmitted from the San Juan Basin to Albuquerque on the state of New Mexico microwave network.

Detailed field studies will be conducted based upon results or from the five continuously recording stations. The field work will include refraction experiments as well as small scale seismicity studies.

Reports

Jaksha, L. H., Locke, Jerry, and Gebhard, H. J., Microearthquakes Near the Albuquerque Volcanoes, New Mexico (Review).

Instrument Development and Quality Control

9970-01726

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Investigations

A prototype microprocessor event recorder built by ARGOS systems is now in the first stage of completion. It is currently being tested and evaluated. This group is also evaluating the Kinemetrics tiltmeter to find ways of improving its accuracy and reliability. Upon completion, these improvements will be implemented on approximately 100 units. Tests are being performed on Bell and Howell VR3700 record and playback units in order to accurately define proper setup procedures.

Results

During the past six months the 100 portable cassette seismic recording systems, while not in the field, have been modified so that all now contain WWVB radios. This will improve their timing accuracy.

Work has been done on two emergency systems. The first is an emergency power generator to keep telemetry systems running in case of power failure. After much investigation, such a system is now in the process of being acquired. The second system is one that will record seismic telemetry that comes in directly on radio links with no telephone lines. This will allow recovery of a limited number of station records in the event a local earthquake causes loss of telephone telemetry. This system will be going on-line immediately.

An interface between a well-logging instrument and a PDP-11/03 computer was completed and has been operating successfully in the field. Work is continuing on documenting and characterizing the Playback Center and preparing for elimination of the 1700 computer. Work is also being done on construction of 5 precision clocks, a new frequency counter for field work and a computer interface for the Terra-Tech systems. During the past six months 200 radios have been modified for telemetry, 150 seismometers have been calibrated and work is continuing on construction of 150 VCO/preamp units and 150 new discriminators.

Southern California Cooperative Seismic Network

9930-01174

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Investigations

1. Investigations conducted using stations of the Southern California cooperative seismic network exclusive of the Imperial Valley are reported here for the period April thru September 1979. 2,849 earthquakes were timed and located in cooperation with Caltech using the Caltech Earthquake Detection and Recording (CEDAR). For a detailed discussion of the results of this investigation refer to C.R. Allen, Southern California Seismic Arrays, 14-08 - 0001 - 16719.

2. We continued *in situ* timing of blasts at Eagle Mountain Mine.

3. We continued the investigation of the Homestead Valley Earthquakes, M_L 4.9, 5.2, of March 15, 1979, north of Yucca Valley, California. All smoked paper records have been timed and continuous playbacks of the first 24 hours of FM recording (March 16) have been obtained. It is estimated that in excess of 6 man-months of effort will be required in processing the more than 3,000 locatable events comprising the sequence.

4. We responded to the October 15, 1979 earthquake (M_L = 6.6 near Mexicali) by deploying 5 smoked paper recorders within 10 hours of the event. These were replaced by seven 5-day FM recorders on March 20 which have remained in operation through the end of October. In addition, we helped coordinate efforts of persons mapping ground breakage, installing alignment arrays, releveling, and other expedient experiments. This effort was supported in part under Imperial Valley Geothermal Studies, 9-9930-01729.

5. We have continued our effort to characterize Southern California seismicity, both regionally and locally, so as to provide a background against which anomalous changes in seismicity might be recognized.

Results

1. More than 2,000 'aftershocks' of the March 15, 1979 Homestead Valley sequence shown in Figure 1 have been timed and located. Surface breaks were complex, comprising two parallel zones of primarily right lateral *en echelon* faulting trending north-northwest in fair agreement

with focal mechanism calculations for the largest shocks. The event sequence was unusual in several respects. The largest event occurred nearly 1 hour into the sequence making the temporal development swarm-like in nature. Despite a spatial extent of over 20 km the events appear to range no deeper than about 3 to 4 km. Initial aftershocks revealed an intriguing cruciform pattern suggesting conjugate faulting followed by the development of a 45 km linear zone trending north-northwest and apparently transecting other major mapped faults.

2. Preliminary locations for about 1,100 aftershocks of the $M_L = 6.6$ Mexicali earthquake of 15 October, 1979 in the Imperial Valley have been calculated for a two week period beginning on October 17 and are shown in Figure 2. The calculation of the mainshock epicenter, south of the international border, was greatly aided by data from the Cerro Prieto network operated by CICESE in Ensenada. The mainshock is located about 10 km southeast of the most southerly mapped ground breakage north of the border and is marked by a distinct lack of aftershocks in its vicinity. Although 30 km of right-lateral surface rupture has been mapped, the aftershocks extend for a distance in excess of 100 km and are most numerous in those areas along the Imperial Fault inwhich swarms predominated prior the event. With time, the aftershock distribution manifests a progressive development to the northwest. An intriguing linear distribution of small quakes can be seen along the eastern edge of the Imperial Valley on trend with the southern San Andreas Fault. First motions exclude the possibility of a vertical strike-slip mechanism and suggest normal faulting with an east-northeast tension axis consistent with subsidence along eastern boundary faults.

3. A surprising change in seismicity rate has been noted with a 30% decrease in activity occurring near the time of the magnitude 7.7 Kern County earthquake in 1952 (Figure 3). Preliminary investigation appear to exclude the possibility that this change is an artifact of processing techniques. Current efforts are directed at determining the spatial extent of the observed change in seismic rate.

Reports

Hutton, L.K., Johnson, C.E., Pechmann, J.C., Ebel, J.E., Given, J.W., Cole, D.M. German, P.T., 1979, Epicentral locations for the Homestead Valley Earthquake Sequence, March 15, 1979: California Geology (in press).

Johnson, C.E. Hutton, L.K., 1979, Tectonic implications of the March 15, 1979 Homestead Valley Earthquake in Southern California: Abstract of a paper to be presented at A G U Annual Fall Meeting, San Francisco, Ca., December.

Hutton, L.K., Minster, J.B., Johnson, C.E., 1979 Seismicity trends in Southern California: Abstract of a paper to be presented at A G U Annual Fall Meeting, San Francisco, Ca., December.

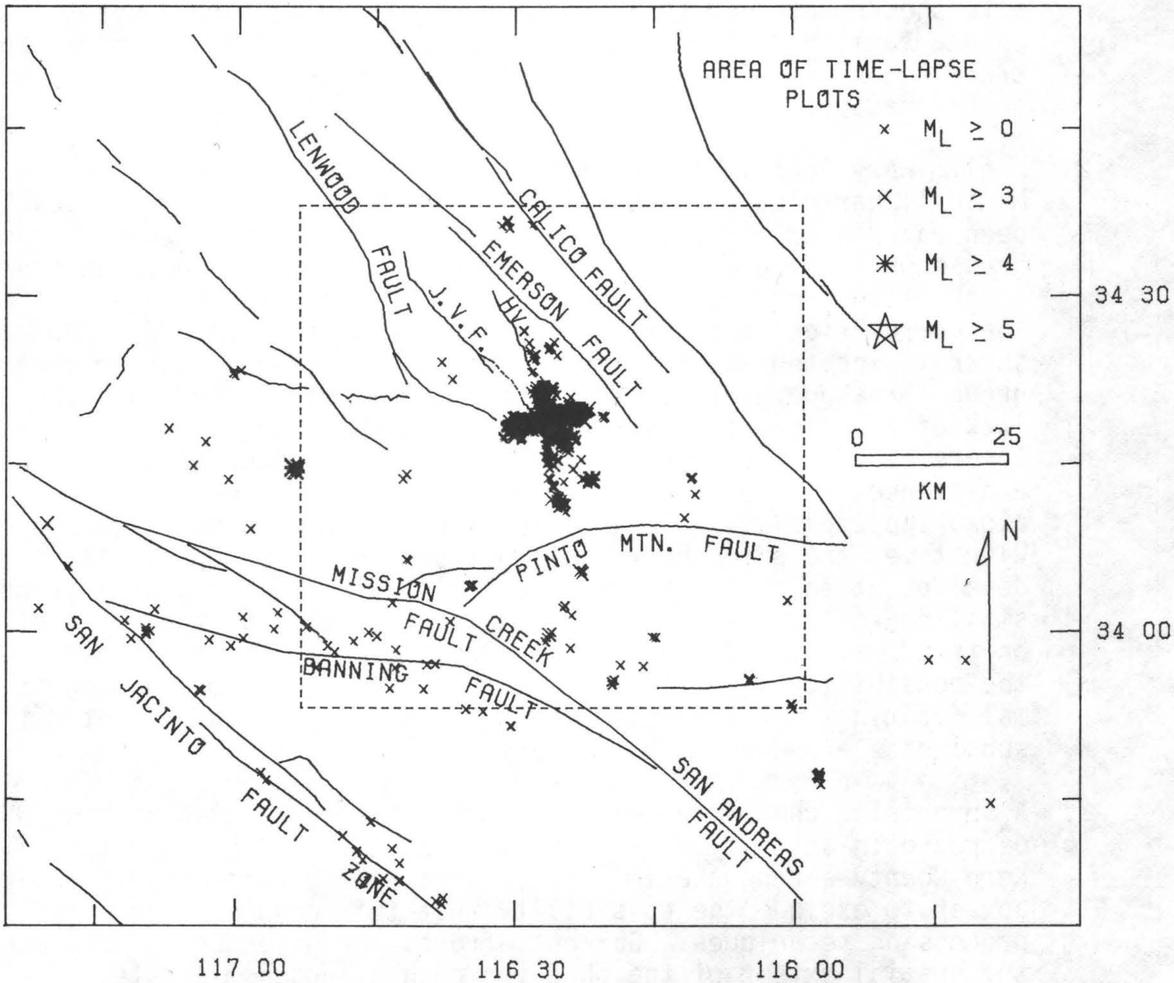

Figure 1. Aftershock distribution of the M_L = 4.9, 5.2 Homestead Valley Sequence of 15 March, 1979.

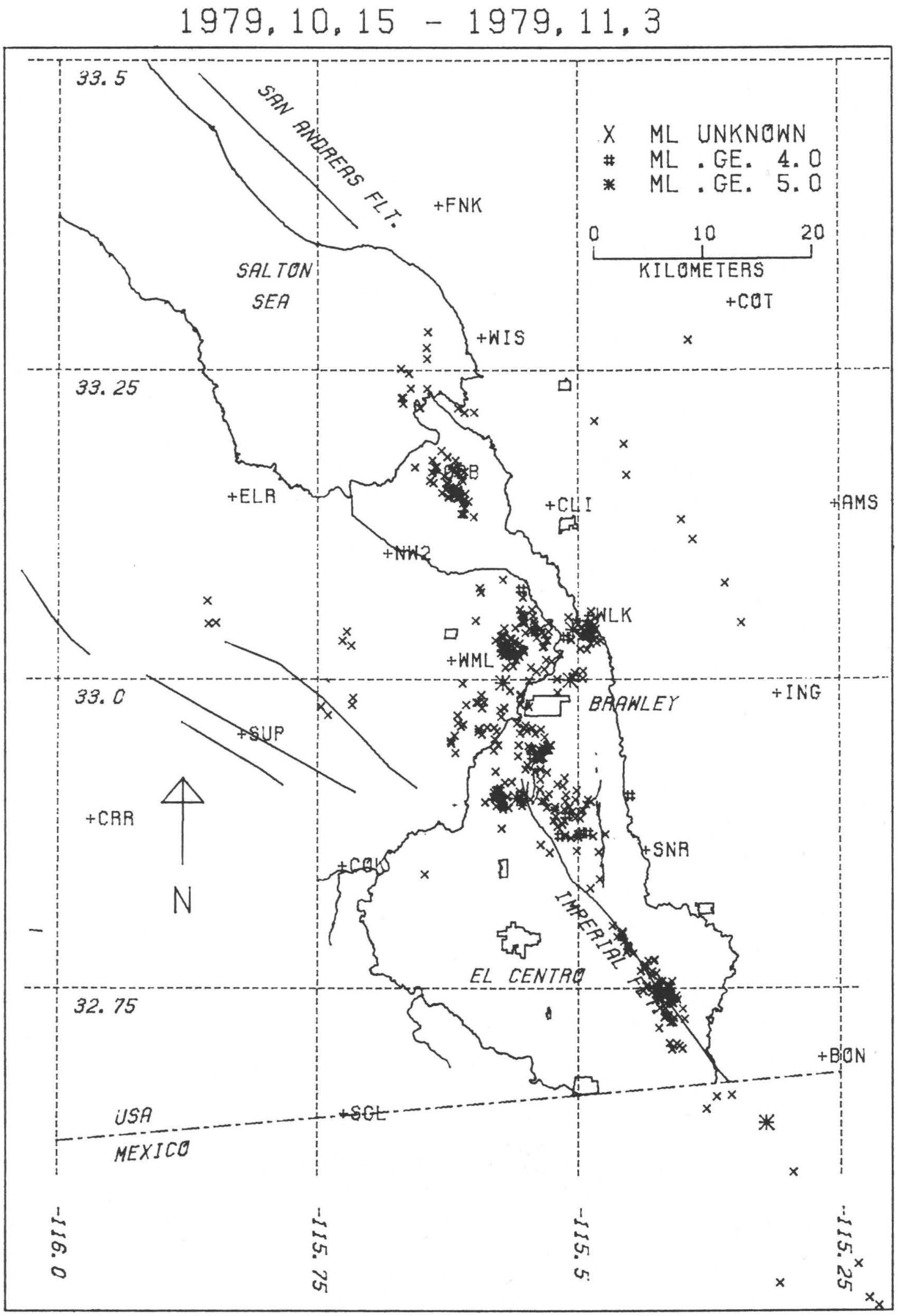

Figure 2. Aftershock distribution of M_L = 6.6 Mexicali earthquake of 15 October, 1979.

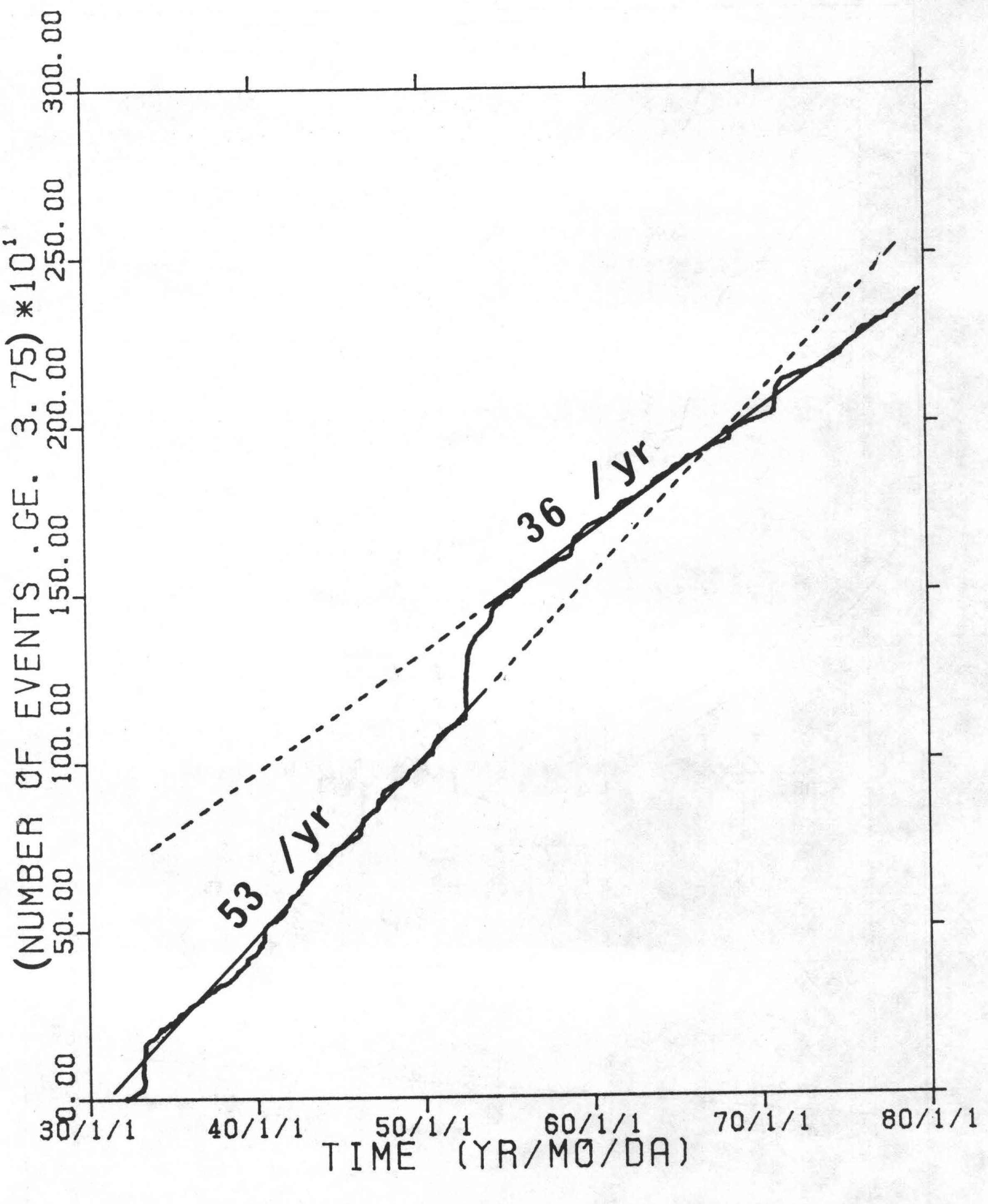

Figure 3. Cummulative number of events exceeding $M_L = 3.75$ since the inception of the Caltech Catalog in 1932. Of particular interests is an apparent 30% decrease in seismic rate occurring near the time of the magnitude 7.7 Kern County earthquake.

Seismological Research Related to Earthquake Prediction and Hazard Reduction

Contract No. 14-08-0001-17631

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Investigations

1. P-velocity monitoring.
Continued monitoring of large quarry blasts that occurred in southern California was made during the contract period.

2. Microearthquake survey for southern California.
Microearthquake surveys with portable seismographic trailers were continued along the San Andreas fault zone between the Salton Sea and Desert Hot Springs during the contract period.

3. Earthquake research using the CEDAR system.

4. Application of earthquake mechanism study to prediction of long-period ground motions.
A semi-empirical approach to the prediction of long-period ground motions resulting from large strike-slip earthquakes was investigated.

Results

1. P-velocity monitoring.
The results for the Mojave and the Victorville blasts are shown in Figure 1. For most of the paths in southern California no changes in P-velocity exceeding 2% have been observed. For the Corona-Riverside path a slight velocity increase was found during the period from 1976 to 1978. This change correlates in time with the U.S.G.S. Geodolite results.

2. Microearthquake survey for southern California.
We have found that the San Andreas fault and the southwest side of the fault between the Salton Sea and Palm Springs are extremely quiet at microearthquake thresholds ($M \sim 1.4$), Figure 2. This documents the existence of a seismic "gap" in this area. The activity northeast of the San Andreas appears to be increased (0.23 ± 0.59 earthquakes/day, 7 to 20 Feb. 1979 and 0.56 ± 0.88, 21 Feb. to 9 Apr. 1979) compared with the results of Brune and Allen (0 earthquakes/day)(1967), however.

3. Earthquake research using CEDAR.
We have taken steps toward the establishment of instrument responses and gains for the SCARLET network operated through the CEDAR system. In view of the strong degree of inhomogeneity of the equipment used at 160 SCARLET stations, the responses have been grouped into three categories: 1) CIT stations 2) U.S.G.S. stations and 3) U.S.G.S. modified by dealiasing filters. The sensors are assumed to meet manufacturer specifications. The degree of accuracy of this calibration is still fairly low, and further refinements are

necessary, but this provides a working basis toward reliable calibration of CEDAR, and permits preliminary amplitude studies.

The Homestead Valley earthquake sequence of March 15, 1979 was the object of a detailed study (Hutton et al., 1979). Over 3000 aftershocks were detected and recorded, and good coverage permitted very accurate relative location as well as a study of the evolution of activity with time.

Using the finalized 1978 Southern California Catalog, and archived data from CEDAR, we have started a comparison of S travel times from well located events with the model currently used in routine location. Results to date show that the assumed Poisson ratio (0.27) is too large, and that a smaller value (0.24-0.25) is more appropriate.

P-travel time curves from events of varying depth in the San Bernardino mountains show that no significant relief in the mid-crustal discontinuities can be detected across this massif, which is not inconsistent with the absence of isostatic adjustment of the range (Clayton and Minster, 1979).

4. Application of earthquake mechanism study to prediction of long-period ground motions.

Predictability of long-period (1 sec or longer) ground motions generated by long strike-slip earthquakes such as the 1906 San Francisco and the 1857 Fort Tejon earthquakes was investigated. The models were constrained at three periods, 1 sec, 10 sec and > 100 sec, by gross seismological data. The results are: (1) the velocity response spectra of ground motions in the near-field are nearly flat at about 50 cm/sec over the period range from 1 to 10 sec under normal conditions; (2) under certain circumstances they can be as large as 150 cm/sec; (3) the maximum duration of the ground motion is 6 min.

Reports

Clayton, N. and J. B. Minster, 1979, Crustal structure near the eastern transverse ranges, Abstract, AGU.

Hutton, L. K., C. E. Johnson, J. C. Pechmann, J. E. Ebel, J. W. Given, D. M. Cole, and P. T. German, 1979, Epicentral locations for the Homestead Valley Sequence, March 15, 1979 (submitted to California Geology).

Kanamori, H., 1979, A semi-empirical approach to prediction of long-period ground motions from great earthquakes, Bull. Seismol. Soc. Am., 69, 1645-1670.

McNally, K. C. and J. B. Minster, 1979, Non-uniform seismic slip rates along the middle American trench (submitted).

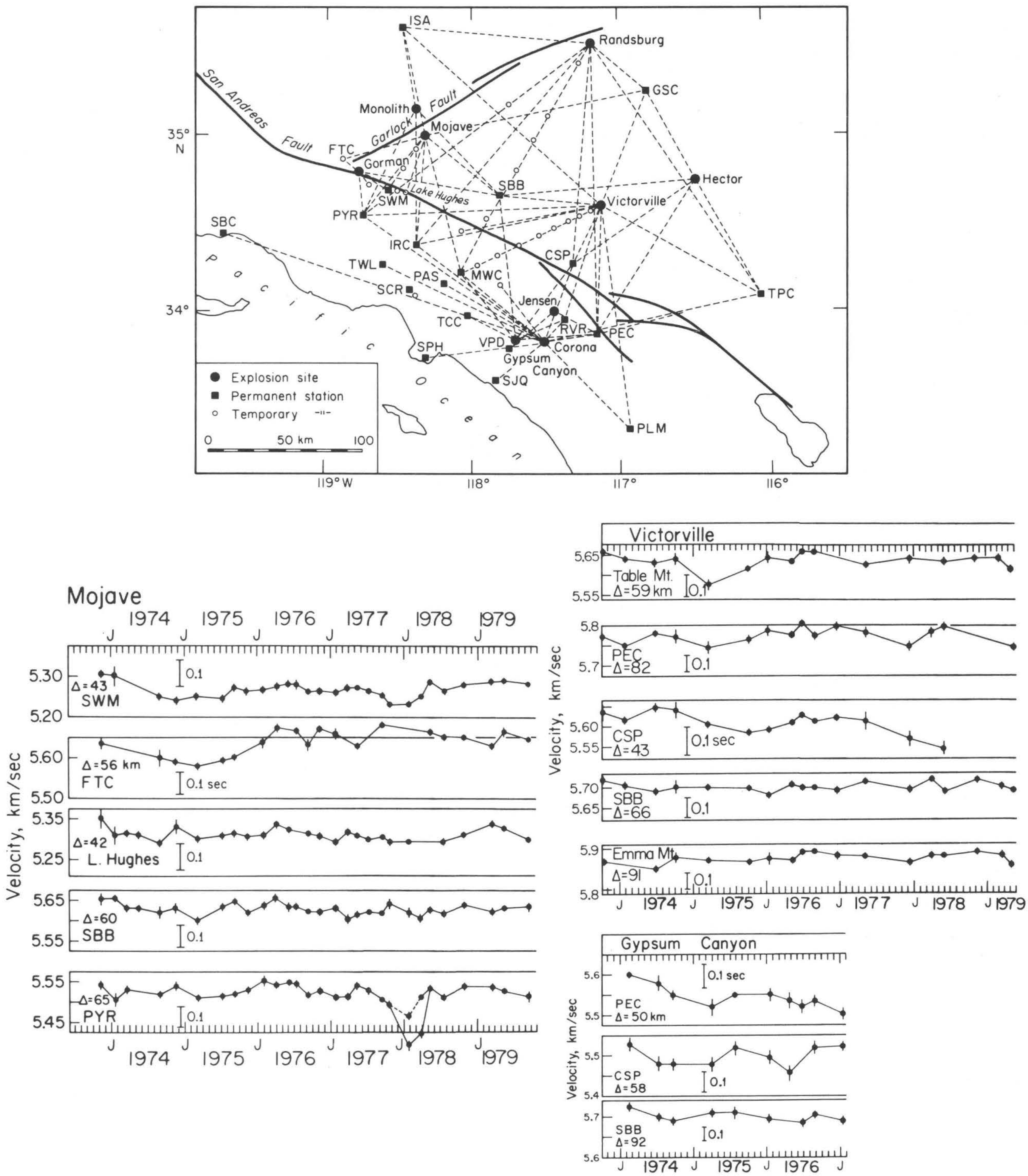

Figure 1. Temporal variation of average velocity obtained from the Mojave and Victorville quarry. The results obtained from the Gypsum Canyon quarry are shown for comparison,(The quarry operation at Gypsum Canyon was discontinued in 1977).

EVENT LOCATIONS 1 Jan to 31 Jun 1979 Velocity model of this study.

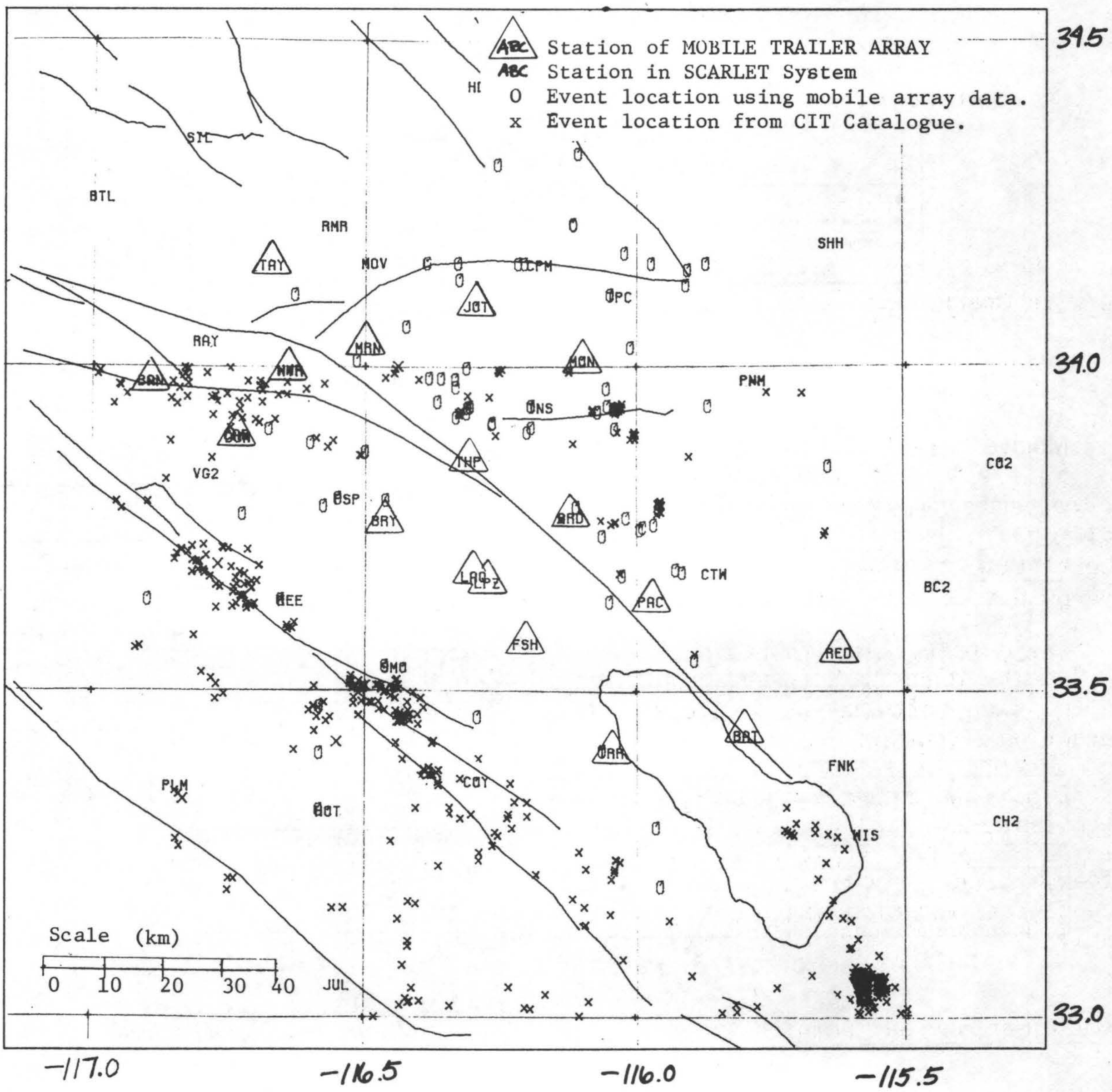

Figure 2

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

14-08-0001-16716

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Network Operations

The 1979 summer field trip was successful. The field party was able to get to all of the seismometer sites and bring the seismic network back up, to re-install one of the tiltmeters and add an additional tiltmeter to the array, and to take gravity measurements at each of the seismometer sites as well as at several other sites on Adak Island. The Adak seismograph network currently consists of fourteen two- component short-period seismometers, and the tiltmeter array consists of eight borehole bubble tiltmeters.

The field party also installed an FM carrier tape recording system, to record the data from the fourteen seismic stations on analogue magnetic tape. When software is developed to read these tapes and to do event detection, routine data analysis will be done entirely interactively from traces portrayed on a computer graphics terminal. Until then, data is being read from Develocorder film records, while routine location of events is now performed with the use of an interactive data terminal linked to a PDP 11/34 computer. This system allows entry of arrival times, phase descriptions, amplitudes, and durations directly into the hypocenter location program, eliminating the need for keypunching of data.

Investigations and Results

Two methods to aid in the determination of focal mechanisms of small to moderate earthquakes from the data gathered by regional networks are being developed. The first of these methods uses the ratio of the maximum S amplitude to the maximum P amplitude as inputs to a procedure for determining a single focal mechanism solution. This method was successfully applied to a group of small earthquakes in a tightly clustered active zone in the southwest region of Adak network coverage. These events preceded a magnitude 5 earthquake, and the method led to the discrimination of true foreshocks of that earthquake.

The second method is based on an objective sorting, by computer, of P-wave first motions from many events into composite focal mechanism solutions. This method is being applied to events in the southeast region of Adak network coverage in a search for premonitory changes in focal mechanisms before the 04 November 1977 magnitude 6.5 earthquake.

The teleseismic focal mechanism of the 04 November 1977 earthquake and two of its largest aftershocks are being determined. Available P-wave first motion data are insufficient to determine the nodal planes of these thrust events, so S-wave data are being analyzed. The S-waves for these events appear complicated on WWNSS seismograms compared, for example, to the 1971 Adak Canyon event. This is due to the occurrence of multiple S arrivals at most stations. The nature of the multiple arrivals is being investigated.

Two sets of data are being studied to better define the seismicity which occurred near Adak prior to the installation of the present seismic network in 1974. The first set of data consists of the arrival times of P- and S-waves from local events at station ADK since 1970. These data show clusters of activity in time. We are trying to determine the spatial distribution of these events by mapping annuli of activity, whose centers are at ADK and whose radii correspond to S-P times. The second set of data consists of PDE hypocenters from 1970. These data show a decrease in the rate of earthquakes in the vicinity of Adak, which started in 1974 and continues through 1977. This change in the rate of teleseismically recorded activity will be studied in more detail.

An additional tiltmeter was installed as part of the Adak tiltmeter network during August 1979, and one of the other seven tiltmeters was reinstalled. All of the tiltmeters currently record a similar tidal signal but differ greatly in terms of response to meterological changes and long term stability. Present analysis is concentrating on intersite stability comparisons and on time series analysis of the the tidal signal.

Reports

Billington, S., 1979, A field study of earthquake prediction methods in the Central Aleutian Islands, presented at the Alaska Science Conference, Fairbanks, Alaska.

La Forge, R., and Engdahl, E.R., 1979, Tectonic implications of seismicity in the Adak Canyon region, Central Aleutians, Bull. Seism. Soc. Amer., v. 69, p. 1515-1532.

Price, S.J., 1979, Distribution in space and time of b-values in the Adak seismic zone, EΦS, v. 60, p. 312.

Alaska Seismic Studies

9940-01162

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Investigations

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

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

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

Results

1. The processing has been completed for 221 aftershocks that occurred within 15 days of the St. Elias, Alaska earthquake of February 1979. The epicenters of these events define a zone about 65 x 80 km in extent lying southeast of the epicenter of the main shock. The areal distribution of the epicenters is highly nonuniform, with a nearly complete absence of activity between the epicenter of the main shock and a clustering of aftershocks about 50 km to the southeast. The depths of most of the aftershocks are poorly controlled, but the better located earthquakes all have depths less than about 35 km. Together with a focal mechanism for the main shock, these data suggest a low-angle thrust as the primary rupture mechanism for the main shock.

The statistical properties of the aftershocks have also been studied. The data set is complete for events with magnitudes ≥ 3.3 starting one day after the main shock. Two of the three largest aftershocks, all with magnitudes between 5.0 and 5.2 m_b, occurred within this time. The b-value of the frequency-magnitude relationship is close to 1.0. The p-value, which describes the rate of decay of seismicity, is 1.1, which is within the range of values normally observed in other regions.

Focal mechanisms have been determined for most of the larger aftershocks.

The compression axis is nearly horizontal in all cases, but the orientation of this axis generally changes from north-south near the epicenter of the main shock to northwest-southeast in the cluster to the southeast.

2. Four portable seismic stations were operated in the aftershock region of the 28 February earthquake during parts of July and August 1979. The data from these instruments will provide depth control in the aftershock locations that will be important in helping to resolve whether the main shock involved primarily inter- or intra-plate rupture.

3. After a long but successful field season all seismic stations but SUK (which was put out of order by a bear in August) are now operating. Two new stations were installed. One is located 40 km north of the St. Elias earthquake rupture zone and will improve aftershock locations. The other is 75 km northeast of Cordova. All but 4 of the 48 vertical seismometers are now using one of the new A1VCO (amplifier-voltage-controlled-oscillator-calibrator) units which have proved to be highly reliable.

4. SMA-1 strong motion instruments were installed at four sites between Prince William Sound and Icy Bay, within the seismic gap that remains between the 1979 St. Elias earthquake and the 1964 Prince William Sound earthquake.

Reports

Hasegawa, H., Stephens, C. D, and Lahr, J. C., 1979, Fault parameters of the St. Elias earthquake of 28 February 1979, Earthquake Notes, Eastern Section, Seismological Society of America, v. 49, no. 4, p. 69.

Lahr, J. C., 1979, HYPOELLIPSE: A computer program for determining local earthquake hypocentral parameters, magnitude and first motion pattern, U.S. Geological Survey Open-File Report, 79-431, 310 p.

Lahr, J. C., Stephens, C. D., Hasegawa, H. S., and Boatwright, J., 1979, Alaskan seismic gap only partially filled by 28 February 1979 earthquake, Science, in press.

Lahr, J. C., Horner, R, B., Stephens, C. D., Fogleman, K. A., and Plafker, G., 1979, Aftershocks of the Saint Elias Mountains, Alaska, earthquake of 28 February 1979, Earthquake Notes, Eastern Section, Seismological Society of America, v. 49, no. 4, p. 69.

Stephens, C. D., Horner, R. B., Lahr, J. C., and Fogleman, K. A., 1979, The St. Elias, Alaska Earthquake of 28 February 1979: Aftershocks and regional seismicity, Amer. Geophys. Union 1979 Spring Meeting Program, p. 60.

Stephens, C. D., Lahr, J. C., and Fogleman, K. A., 1979, Seismicity Before and After the St. Elias, Alaska Earthquake of 28 February 1979, presented at the 30th Annual Alaska Science conference, September 19-21, 1979, Fairbanks, Alaska.

Stephens, C. D., and Lahr, J. C., 1979, Seismicity in southern and south eastern Alaska, in: The United States Geological Survey in Alaska: Accomplishments during 1978, Geological Survey Circular 804B.

Von Huene, R., Moore, G. W., Moore, J. C., and Stephens, C. D., 1979, Cross Section, Alaska Peninsula-Kodiak Island-Aleutian Trench: Summary, Geol. Soc. Amer. Bull., Part 1, v. 90, p. 427-430.

Puerto Rico Seismic Program

9950-01502

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Investigations

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

Results

1. A series of seismicity maps of Puerto Rico, the Puerto Rico and Virgin Island area, and the Carribean region are being compiled at various scales. These maps will show both the historical and recent seismicity.

2. Composite focal mechanism solutions have been computed from earthquakes in the Guayanilla Canyon and the Mayaguez area. Eight other composites are in process for concentrations of earthquakes on and near the island.

3. A catalog of 3,540 Puerto Rican earthquakes and 193 on-island quarry blasts has been published (Dart and others, 1979). A circular, describing a selected set of earthquakes listed in the catalog, is currently in review.

Report

Dart, R. L., Carver, D., Wharton, M. K., and Tarr, A. C., 1979, Puerto Rico seismic program seismological data summary, July 1, 1975-December 31, 1977: U.S. Geological Survey Open-File Report 79-870, 138 p.

Seismic Data Library of WWSSN Seismograms

9930-01501

W. H. K. Lee
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U.S. Geological Survey
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(415) 323-8111, ext. 2630

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

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

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Investigations

This semi-annual summary report covers the six-month period from 1 October 1978 to 31 March 1979. The objective of this contract is to conduct a seismic noise survey to identify sites on Long Island with low enough background noise to record local and regional earthquakes and thereby increase the geographical coverage of the Northeastern U.S. Seismic Network (NEUSSN), and to install two permanent seismograph stations on these sites.

Results

Portable seismographs with one-second vertical geophones were deployed at twenty different sites on Long Island. The background noise was determined to be of two distinct types: low amplitude, low frequency (2 Hz) natural microseismic activity probably caused by local surf action and higher amplitude, high frequency (>10 Hz) culturally-related noise probably caused by vehicular traffic, machinery and the moving about of people. The best sites represent a trade-off between these two sources of background noise. Two sites were found that would make excellent permanent seismic stations: on Shelter Island in eastern Long Island and on Lloyd's Neck in north-central Long Island. While conducting this study a magnitude 3.5 earthquake occurred in Cheesequake, New Jersey and was felt on Long Island. This earthquake was not recorded by our instruments, but a noninstrumental (felt) survey of macroseismic information was conducted and more than forty felt reports were logged. These felt reports were classified according to the modified Mercalli scale. The maximum intensity observed in Nassau and Suffolk counties were III. The relationship between intensity and distance observed in this study was not in agreement with Chandra's formula for the northeastern United States. This discrepancy suggests that the earthquake energy has been attenuated across Long Island to a greater extent than predicted by Chandra's formula, possibly due to the thick sedimentary cover.

Reports

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

SUMMARY OF SEMI-ANNUAL TECHNICAL REPORT

Title: A Study of Earthquake Prediction and the Tectonics of the Northeastern Caribbean: a Continuing Experiment in Two Major Seismic Gaps

Principal Investigators: Dr. A. Murphy and Prof. L. R. Sykes

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

Duration of Contract: 1 November 1977 — 31 October 1979

Contract Number: USGS-14-08-0001-16748

Government Technical Officer: Dr. J. F. Evernden

Semi-Annual Technical Report Number 3

Status of Seismic Network

A short-period, radio telemetered network of 17 seismic stations in the northeastern Caribbean continues in good working order. Of the 17 stations, one has a three component set of seismometers, 10 have a vertical and horizontal, and the remainder have only vertical seismometers. The three component set of long-period seismographs has been installed and is fully operational. The vertical component has a peak magnification of 2.5k at about 25 sec while the two horizontals are about 1.5k.

The Digital Event Recording System was installed and operational by the first week in April 1979. The system is being tested/operated with analog triggers. These will be replaced with the digital trigger system during the first week of August. An analog copy of a "typical" earthquake recorded by the system is shown in Figure 1.

Significant Observations from On-Going Research

Earthquakes located by five or more stations of the network between July 1977 and December 1978 are shown in Figure 2. A striking aspect of this seismicity is the large number of events between 64.1° and 65.1°W at about 19°N. Small knots of activity can be discerned within this group. Many of these knots were formed during swarms (localized surges of equal-sized events) and will be discussed in subsequent paragraphs.

Figure 2 also shows isolated clusters of activity near prominent topographic features of the area. Three clusters of events occurred along the northern wall of the Virgin Islands basin, south of the islands of Vieques and St. Thomas. Two groups of shocks are positioned near the northeastern extension of the Anegada pasasge, near 19°N, 63°W. An important burst of activity occurred along the outer wall of the trench at 20°N, 64.8°W.

The seismicity between 18°-19.4°N and 64°-66°W can be more easily understood by viewing vertical cross-sections. Figure 3 presents the hypocenters projected onto a vertical plane oriented parallel to the trench and the island arc (east-west). The events plotted occurred between 18° and 19.4°N. Shocks originating in the Virgin Islands basin were not plotted. Figure 3 indicates that the majority of events less than 20 km deep do not overlap the events that cluster between 64.1° and 64.5°W at 20-50 km depth. Intermediate-depth activity extends to 120 km depth and may deepen to the east.

A cross-section oriented north-south (Figure 4a), containing events located between 64° aand 66°W, shows that earthquake foci from 25 to 120 km depth align along a downgoing seismic zone (DSZ) that dips to the south at 45° beneath the Virgin Islands platform. This activity presumably occurs within the upper portion of a subducted piece of the North American plate. Shallow activity (generally above 20 km depth) is separated from the upper portion of the DSZ. Its position above the upper end of the DSZ suggests that this shallow activity represents seismicity associated with the interface between the North American and Caribbean plates (see Figure 4b). Thus, the events between 25-50 km depth north of Anegada Island (see Figures 2 and 3) are situated <u>within</u> the subducted slab. The area around 19°N, 65°W, however, appears to be a locus of inter-plate seismicity.

One of the major observations of the network is the frequent occurrence of earthquake swarms. We have developed an algorithm for detecting these swarms. The area between 18.6° and 19.4°N and 64° and 65.2°W was divided into 96 subregions each 0.1° on a side. The number of events that occurred in each region was counted, and an average per month was calculated for the period July 1977 through December 1978 along with the standard deviation for each region. When the number of events in any region per month exceeded the average for that region plus two standard deviations, that month was checked to see if this was produced by a main shock-aftershock sequence. If these events were a series of nearly equal-sized events, they were designated as a swarm. Swarms in other areas outside of this broad region were easily determined, since those areas normally produced very few events, and swarms were easily recognized.

The swarms detected by this criterion are shown by boxes in Figure 5. It is clear that these swarms occur in different areas and in several different tectonic regimes. Some of the environments that generated the swarms include the region beneath the inner wall of the Puerto Rico trench near 19°N, 65°W; one portion of the outer wall of the trench; and a zone 40 to 50 km deep within the North American plate near 19°N.

During the period of observation by the network, shallow swarms that occurred at 19.2°N, 64.9°W and 19.1°N, 64.7°W were always accompanied (within 27 days) by a swarm at 40-50 km depth near 19°N, between 64° and 64.6°W. We feel this to be the result of a non-random process. The swarms at 19.2°N, 64.9°W and 19.1°N, 64.7°W were separated on the average of 307 days. The deeper sources produced swarms on the average of 292 days. The pairing of these two regions within a 27 day interval over four consecutive instances appears to be significant when compared to the average repeat time for the swarms. Although the reason for this pairing is unknown, the observation may signify an important empirical method for predicting the occurrence of swarms in this area for the future.

FIGURE CAPTIONS

Figure 1: Analog playback from the digital recording system showing "typical" earthquake. Tick marks represent on second.

Figure 2: Earthquakes located by the Lamont network, July 1977 through December 1978. Note the cluster of events north of the Virgin Islands and the concentration of activity along the north wall of the Virgin Islands basin.

Figure 3: Vertical cross-section oriented east-west along 19°N showing the better-constrained events located by the network. This projection contains events between 18° and 19.4°N, excepting shocks along the Virgin Islands basin. The tick marks on the horizontal and vertical axes are 50 km apart. In all cross-sections, squares represent events to the left of the cross-section line when viewed toward the right-hand endpoint. Diamonds denote events to the right of the plane of the cross-section.

Figure 4: a) Vertical cross-section oriented north-south along 65°W, showing events that occurred between 64° and 66°W. The tick marks on the vertical axis are 50 km apart. Above the cross-section a profile of the sea floor (with vertical exaggeration) along 65°W is shown. Note the downgoing seismic zone between 25 and 120 km depth that extends below the southern wall of the Virgin Islands basin actually occurred beneath the north wall of the basin.

Figure 5: Swarms occurring in the northeastern Caribbean from May 1976 through December 1978. Circles represent larger events ($M \geq 4$ 1/2) that did not occur during swarms. "Major swarms" are sequences whose largest event was of magnitude greater than 4. Note that some areas generated more than one swarm during this time interval. Many swarms were produced near 19°N.

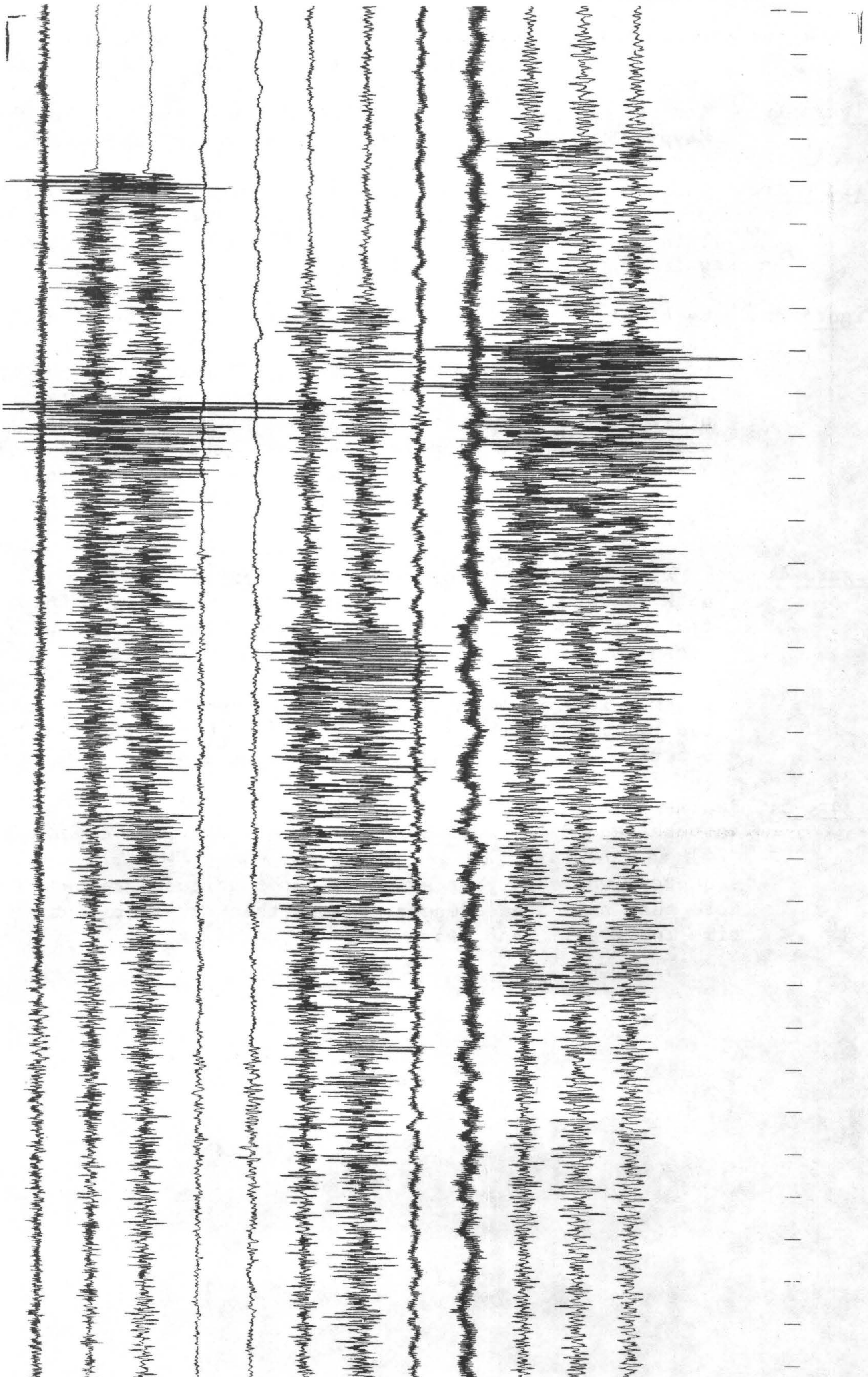
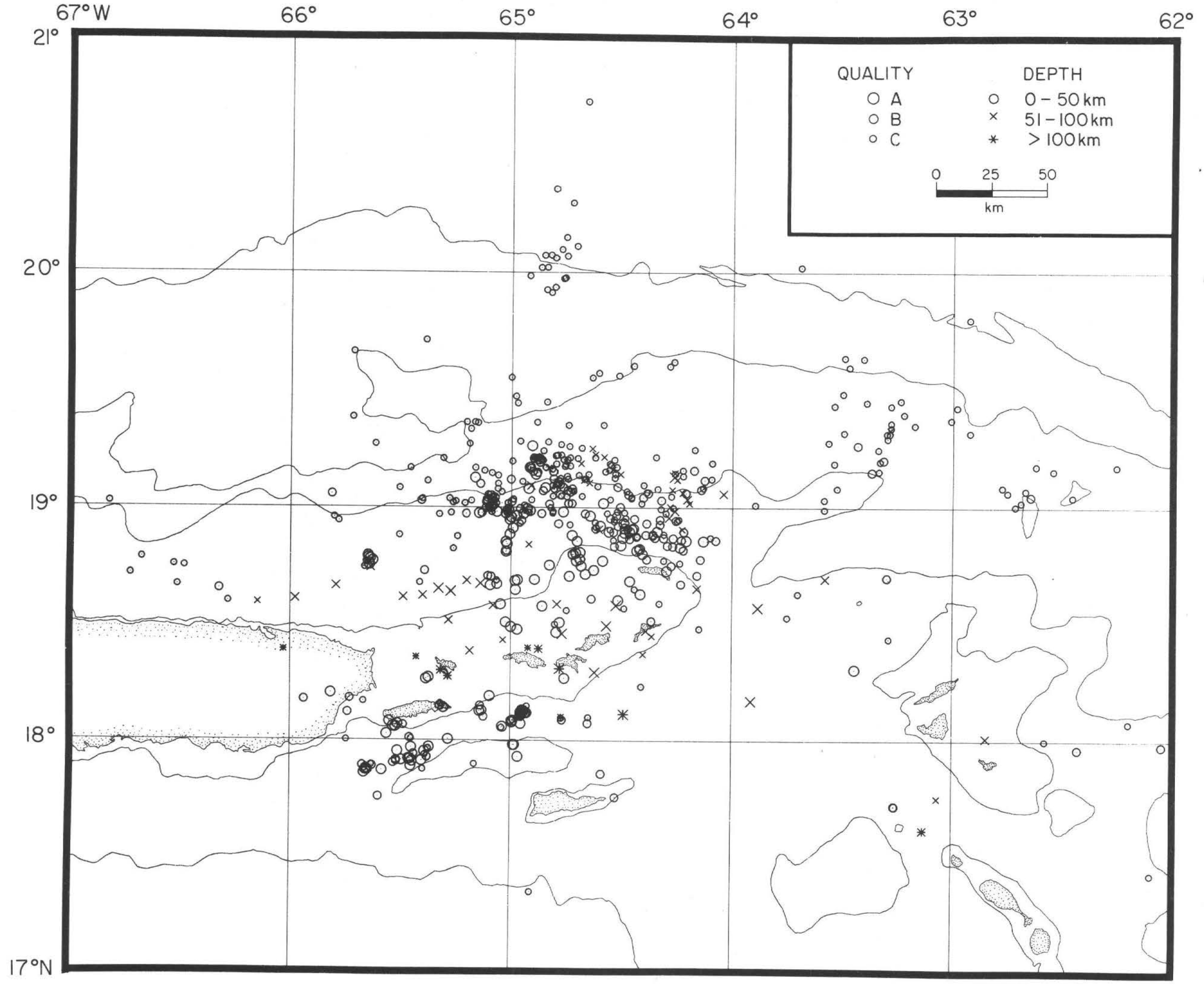


Figure 1

Figure 2



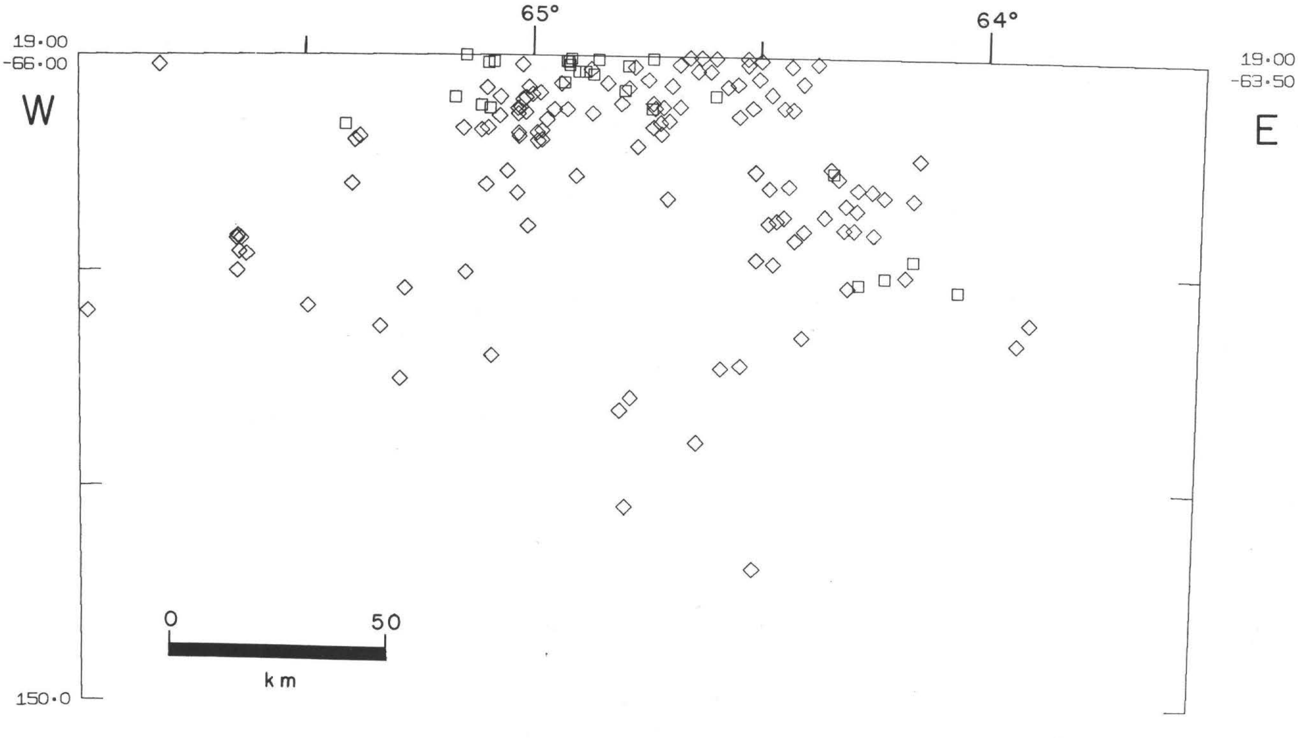


Figure 3

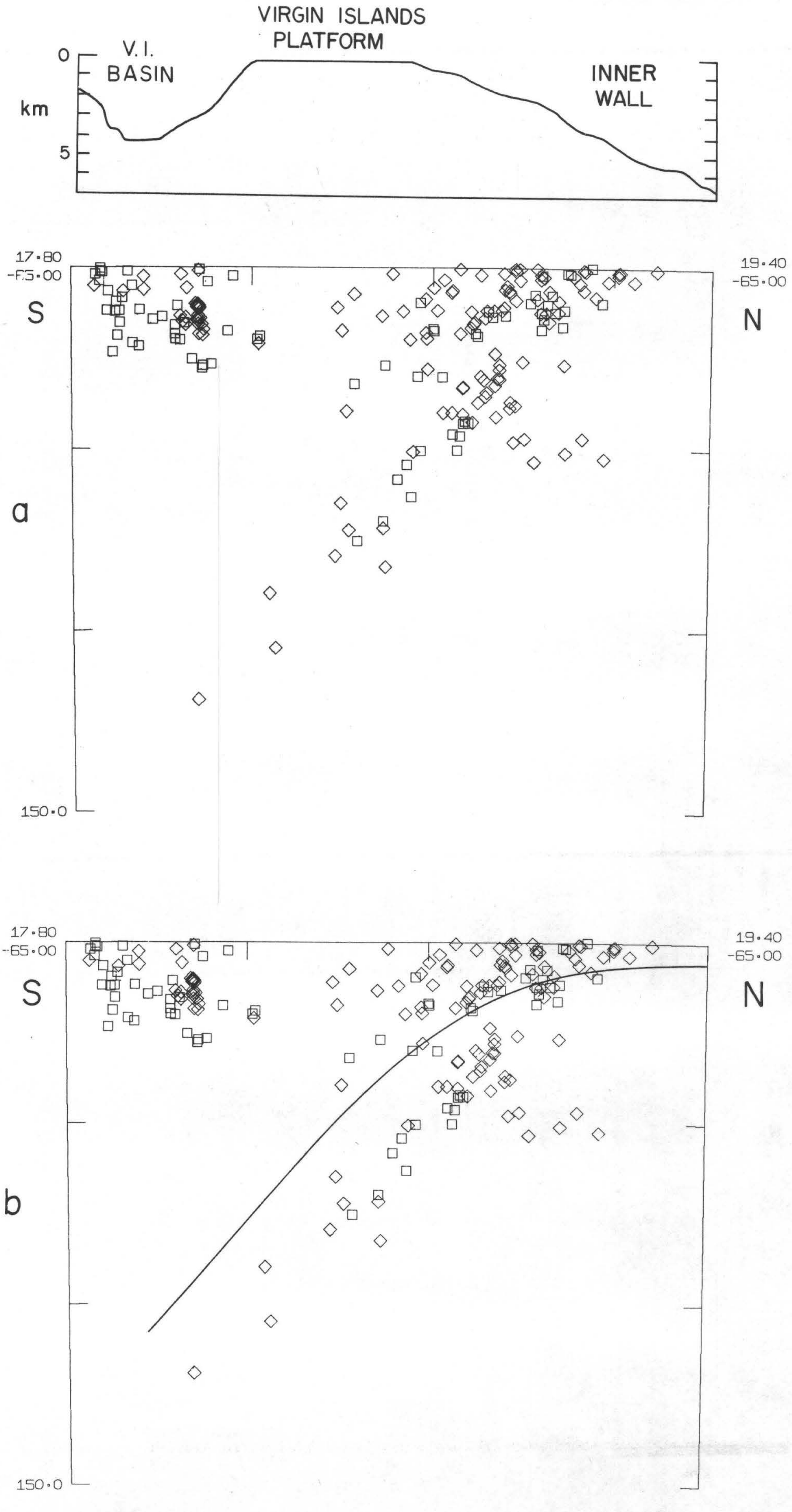

VIRGIN ISLANDS
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Figure 4

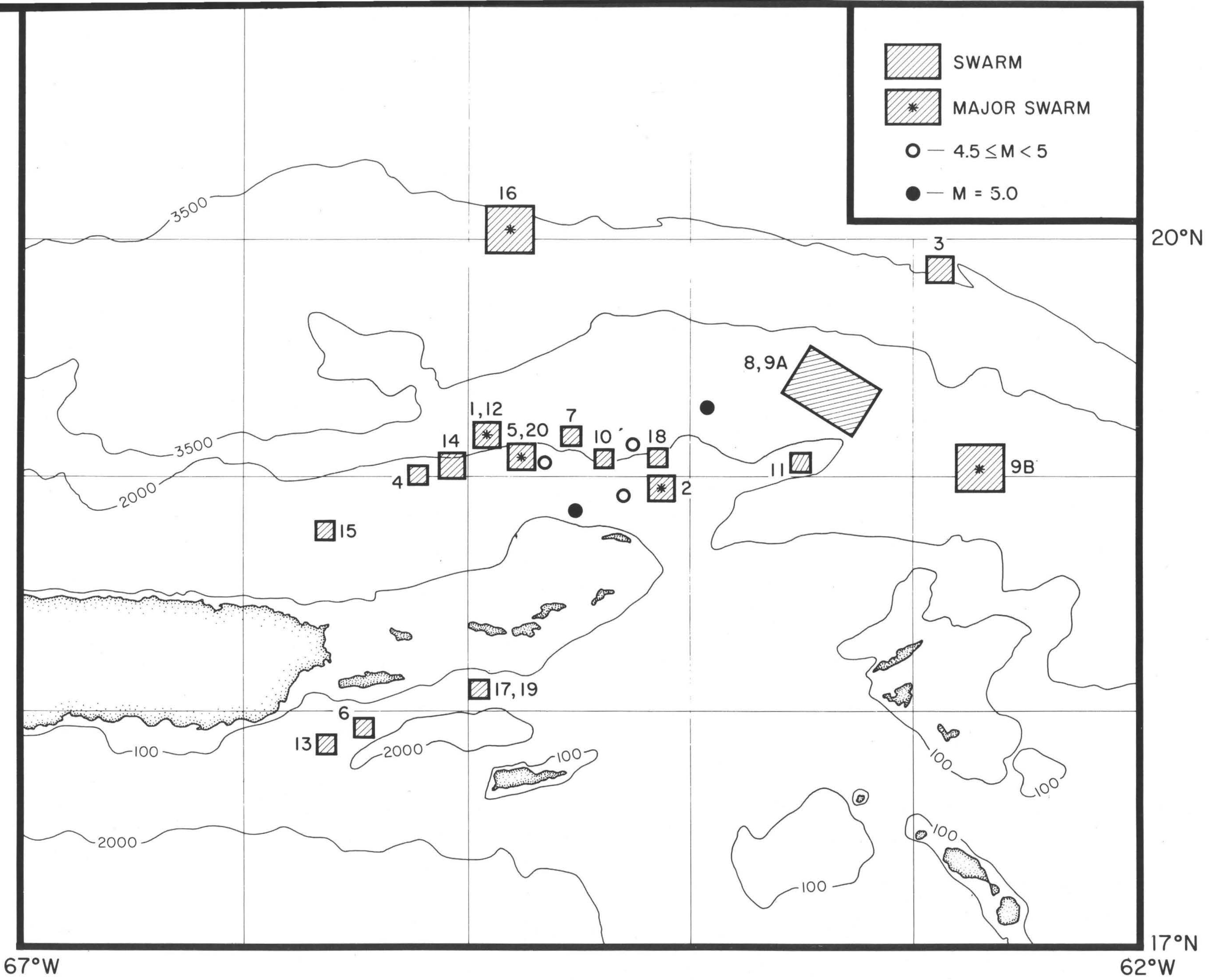
SWARM
MAJOR SWARM
4.5 ≤ M < 5
M = 5.0
20°N
17°N
67°W
62°W
3500
2000
100
16
3
8, 9A
1, 12
5, 20
7
10
18
14
4
11
9B
2
15
17, 19
6
13

Figure 5

G.A.

GLOBAL SEISMOGRAPH NETWORK-EVALUATION AND DEVELOPMENT

9920-02384

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Investigations

1. Development of procedures for more accurate steady-state calibration of the seismic research observatories (SRO); derivation of SRO system transfer functions; evaluation of SRO tests and calibration; preparation of a report describing SRO test procedures and summarizing results.

2. Preparation of a "Data User's Guide to the Global Seismograph Network"; a comprehensive description of WWSSN, HGLP, ASRO, SRO, and digital WWSSN instruments, calibration techniques, test procedures, and data formats.

3. Test, calibration, and evaluation of the prototype digital WWSSN system.

Results

1. Major results of SRO test and calibration studies have been summarized in a report submitted to the Branch for review. The report contains detailed descriptions of test and calibration procedures and an analysis of results with sections on the test program, calibration, noise studies, linearity, and derivation of system transfer functions. Computer programs have been developed for fitting individual transfer functions to measured data.

2. Additional information has been compiled for the "Data User's Guide" and a second draft of the document is in preparation.

3. Calibration and evaluation tests of the prototype DWWSSN system are underway with preliminary indications that fundamental design goals are being met.

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

Contract 14-08-0001-16741

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Earthquake occurrence and geologic structure. Relationships between earthquake occurrence and geologic structure are clarified by the analysis of data from local networks in the areas around Reno and Mina, Nevada. Nearly 2000 hypocenters have been determined, covering the periods May 1973 to October 1978 for the Reno network, and July 1974 to October 1978 for the Mina network. Figure 1 shows the distribution of these events, together with major fault zones (Wright, 1976). Much of the seismic activity appears to be associated with specific fault segments or their terminations or intersections with other structures. A large number of events northwest of Bishop, California correlate well with a diverging cluster of faults at the north end of the 1872 rupture zone in Owens Valley. Clusters of earthquakes occurred in the fall of 1978 near Steamboat, 10 km south of Reno, Nevada and in Diamond Valley, California, at the northern and southern terminations of the 70-km long Genoa fault zone that bounds the eastern flank of the Carson Range. Investigations in the Carson City area by Pease (1979) indicate that the Genoa fault has had at least two distinct movements in the last 4,000 years, and 3-4 movements in Holocene time: the most recent offset had a vertical component of 4-7 meters. In some regions, seismicity appears to be distributed in zones of dispersed faulting, as in the area to the southeast of Walker Lake, or in zones of active volcano-tectonic processes, as in the east end of Mono Valley. In other regions, zones of seismic quiescence correlate with areas of deformation by warping, as in the region north of Mono Lake and west of Walker Lake (Gilbert and Reynolds, 1973), or with areas where magma resides in shallow reservoirs, as in Long Valley.

Non-stationary seismicity along the eastern front of the Sierra Nevada. The seismic flux along the Sierran frontal zone is illustrated in Figure 2. The seismic flux is represented in terms of the energy-equivalent frequency of magnitude 2 earthquakes. We distinguish two non-stationary features in this data. Firstly, over the past 3 years there has been a general increase in seismic activity. Secondly, a one-year period of relative quiescence in 1977-1978 was followed by an abnormally high occurrence of moderate magnitude earthquakes (M_L 3.5-5.5) along the entire zone during late 1978 and the first half of 1979.

Earthquake sequence near Doyle, California. At 15:57:29.0 GMT on 22 February an earthquake of magnitude 5.2 (M_L) occurred near Doyle, California. The hypocentral determination of the event is 39.992°N, 122.105°W, focal depth 9.6 km. The epicenter is about 70 km southeast of Susanville, California, on the Fort Sage fault which ruptured in 1950 during a magnitude 5.6 earthquake. The main shock was preceded by an event of magnitude 3.3 at 07:16 on 22 February, and was followed by 24 aftershocks with magnitudes in the range 1.1-3.1, ending with a small event on 8 March.

References

Gilbert, C. M., and M. W. Reynolds (1973). Character and chronology of basin development, western margin of the Basin and Range province, Bull. Geol. Soc. Amer., 84, 2489-2510.

Pease, R. C. (1979). Scarp degradation and fault history near Carson City, Nevada, Univ. Nevada MS Thesis, 95 pp.

Wright, L. (1976). Late Cenozoic fault patterns and stress fields in the Great Basin and westward displacement of the Sierra Nevada block; Geology, 4, 489-494.

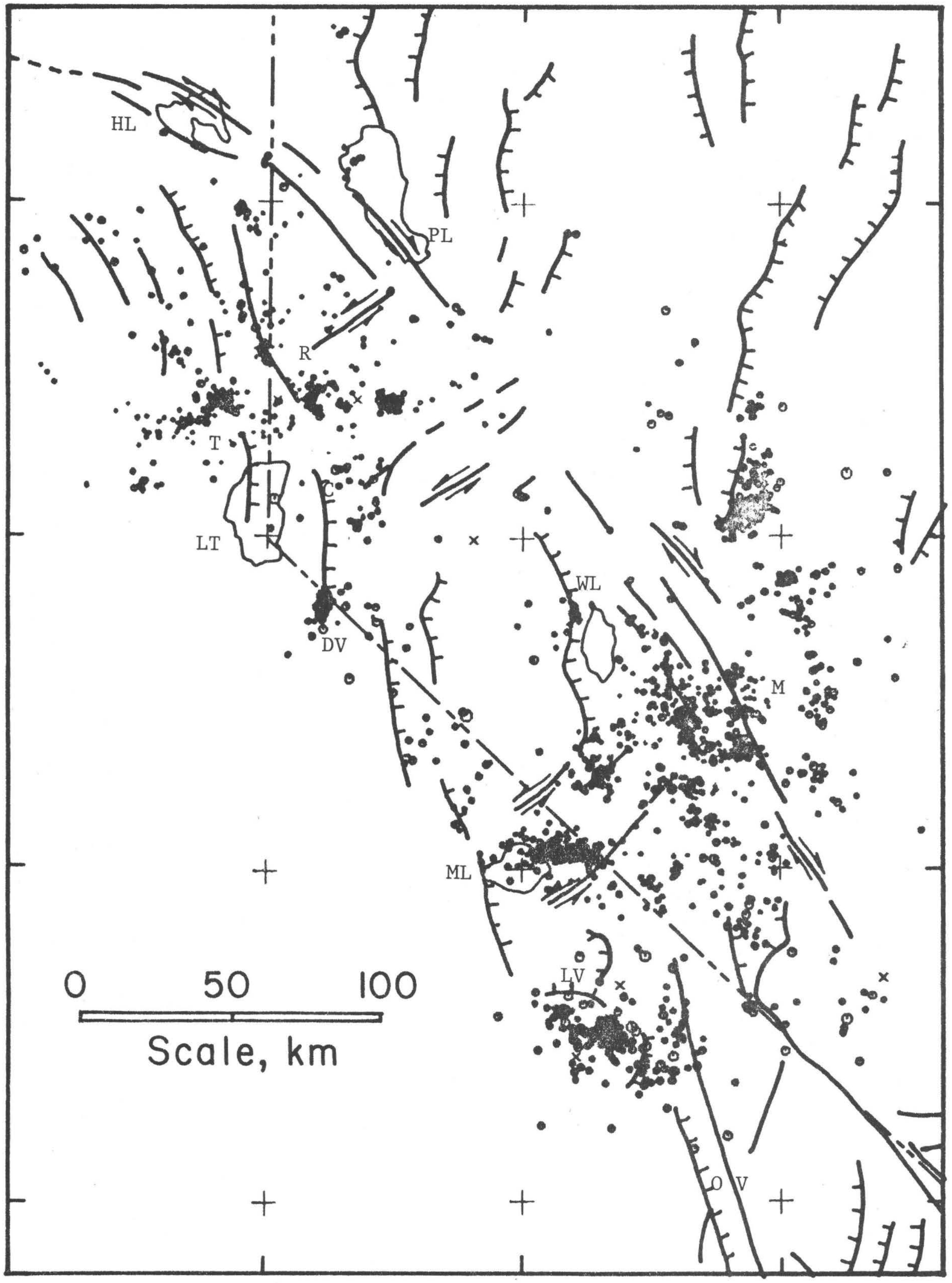

Figure 1. Earthquake epicenters determined from networks in the regions around Reno (May 1973 to October 1978) and Mina (July 1974 to October 1978): the coverage is inhomogeneous.

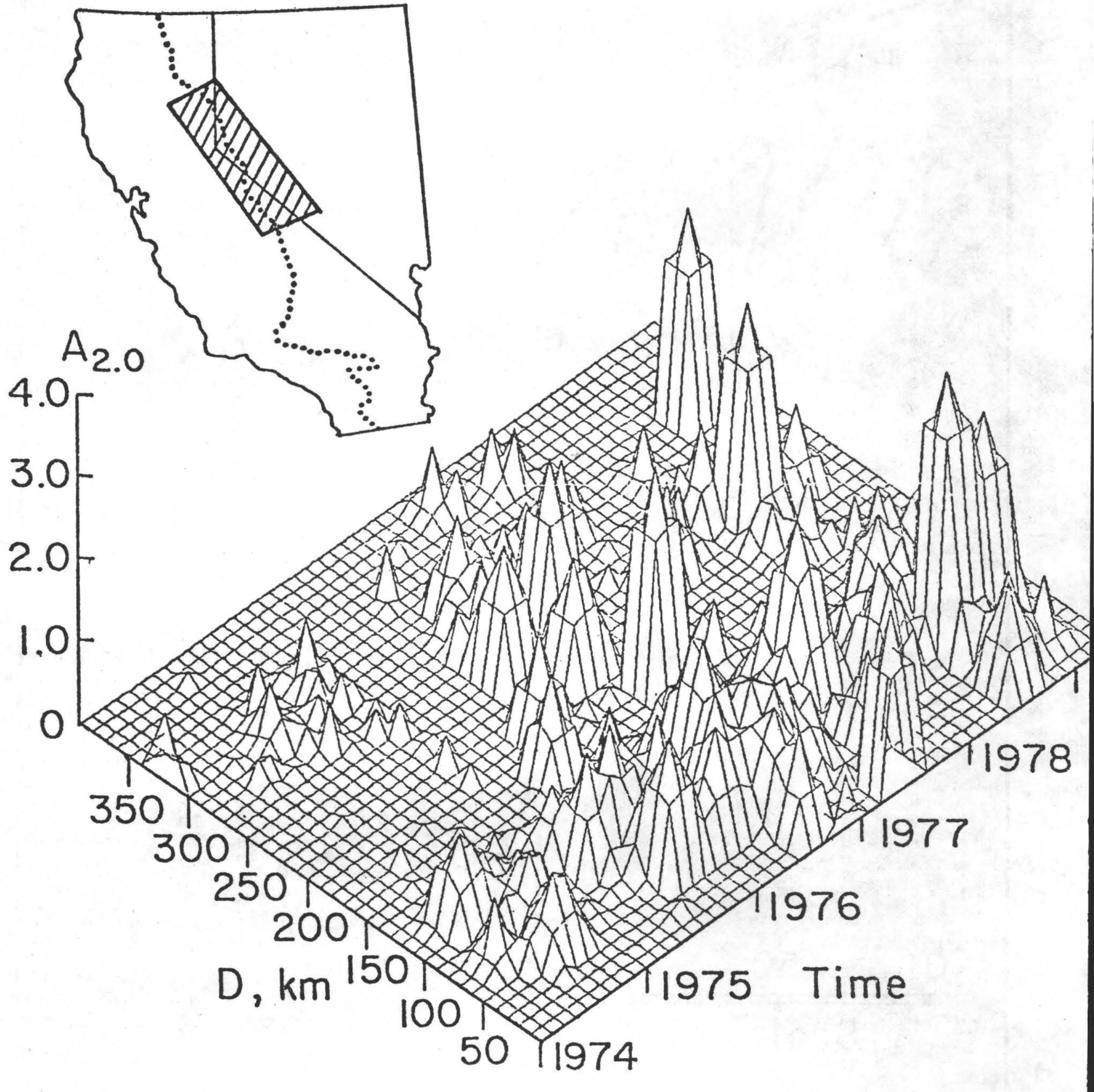

Figure 2. Seismic flux along the eastern front of the Sierra Nevada, represented in terms of energy-equivalent frequency of magnitude 2 earthquakes.

EARTHQUAKE PREDICTION STUDIES IN PAKISTAN

USGS 14-08-0001-16749

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Investigations

The active tectonics of continental convergence in the Himalayas of northern Pakistan and of continent-continent transform faulting in western Pakistan are studied primarily from seismic network data. The tectonics of this area are compared to the central Himalaya and other convergent zones.

Results

The details of the seismicity in the Himalaya and the essential features of other available surface and subsurface data are fitted into a new simple model of the active tectonics. In this scheme there are three main elements: a subducting basement slab, the Indian shield; a passive, underthrusted basement slab, the Tibetan slab; and a sedimentary wedge stretching above the subduction zone and decoupled from both basement slabs.

The fundamental active thrust fault of the Himalaya is located on the upper surface of the subducting slab. The Detachment is the portion of this fault between the subducting slab and the sedimentary wedge. The Basement Thrust is the portion of this fault between the interacting slabs. The Basement Thrust Front is the line separating the very shallow-dipping Detachment from the steeper-dipping Basement Thrust. The Basement Thrust is subdivided into a narrow seismically active portion at the BTF, and, further down-dip, into an aseismic but presumably still active portion of the unknown extent. The narrow belt of thrust earthquakes at the BTF is correlated with the pronounced topographic step between Lesser and High Himalaya and a small circle fitted to the Himalayan "arc".

The scattered seismicity in Tibet, north of the thrust earthquake belt, is associated mostly with normal faulting and is consistent with east-west extension. None of the available solutions for this area are consistent with slip on a shallow-dipping fault. On the other hand, the great Himalayan earthquakes occur south of the BTF, below the sedimentary wedge and are Detachment slip events. In the interseismic periods between the great events thrust earthquakes are concentrated at the BTF and the Detachment appears to be aseismic. This observation is crucial for correctly estimating the seismic hazard along the Himalayan arc.

In Figure 1 a comparison in scale and structure is made between this model for the central Himalaya, the southern Appalachians and the Gulf of Alaska. The main features of the three structures are remarkably similar. In all three cases there is a sedimentary wedge (usually referred to as an accretionary prism in the case of oceanic subduction) detached from the underlying basement. This detachment merges down-dip into a basement thrust. The basement block forming the hanging wall of this thrust provides the support on the hinterland side of the wedge.

Reports

Seeber, L., and J. Armbruster, Seismicity of the Hazara Arc in Northern Pakistan: Decollement vs. Basement Faulting, Geodynamics of Pakistan, A. Farah and K. DeJong (eds.).

Seeber, L., J. Armbruster, and S. Farhatulla, Seismic hazard at the Tarbela Dam Site and surrounding region from a model of the active tectonics, to be published in the University of Peshwar Bulletin.

Armbruster, J., L. Seeber, R. Quittmeyer, and A. Farah, Seismic network data from Quetta, Pakistan: The Chaman Fault and the fault related to the 30 May 1935 earthquake, to be published in the Memoirs of the Geological Survey of Pakistan.

Seeber, L., R. Quittmeyer, and J. Armbruster, Seismotectonics of Pakistan: A review of results from network data and implications for the Central Himalaya, Structural Geology of the Himalaya, P.S. Saklani (ed.), U. of Delhi, 1979.

Seeber, L., J. Armbruster, and R. Quittmeyer, Seismicity and continental subduction in the Himalayan Arc, in preparation for Inter-Union Commission on Geodynamics.

References

Brown, L., D. Allbaugh, J. Brewer, F. Cook, L. Jensen, S. Kaufman, G. Long, J. Oliver, S. Schilt, and D. Steiner, Structure of the continental crust: New results from COCORP Seismic Reflection Profiling, EOS, 60, no. 18, p. 313, May 1979.

Lahr, J.C., R.A. Page, and J.A. Thomas, Catalog of earthquakes in South Central Alaska, April-June 1972, U.S. Geological Survey Open-File Report, 1974.

Plafker, G., Tectonic deformation associated with the 1964 Alaska earthquake, Science, 148, p. 1675, 1965.

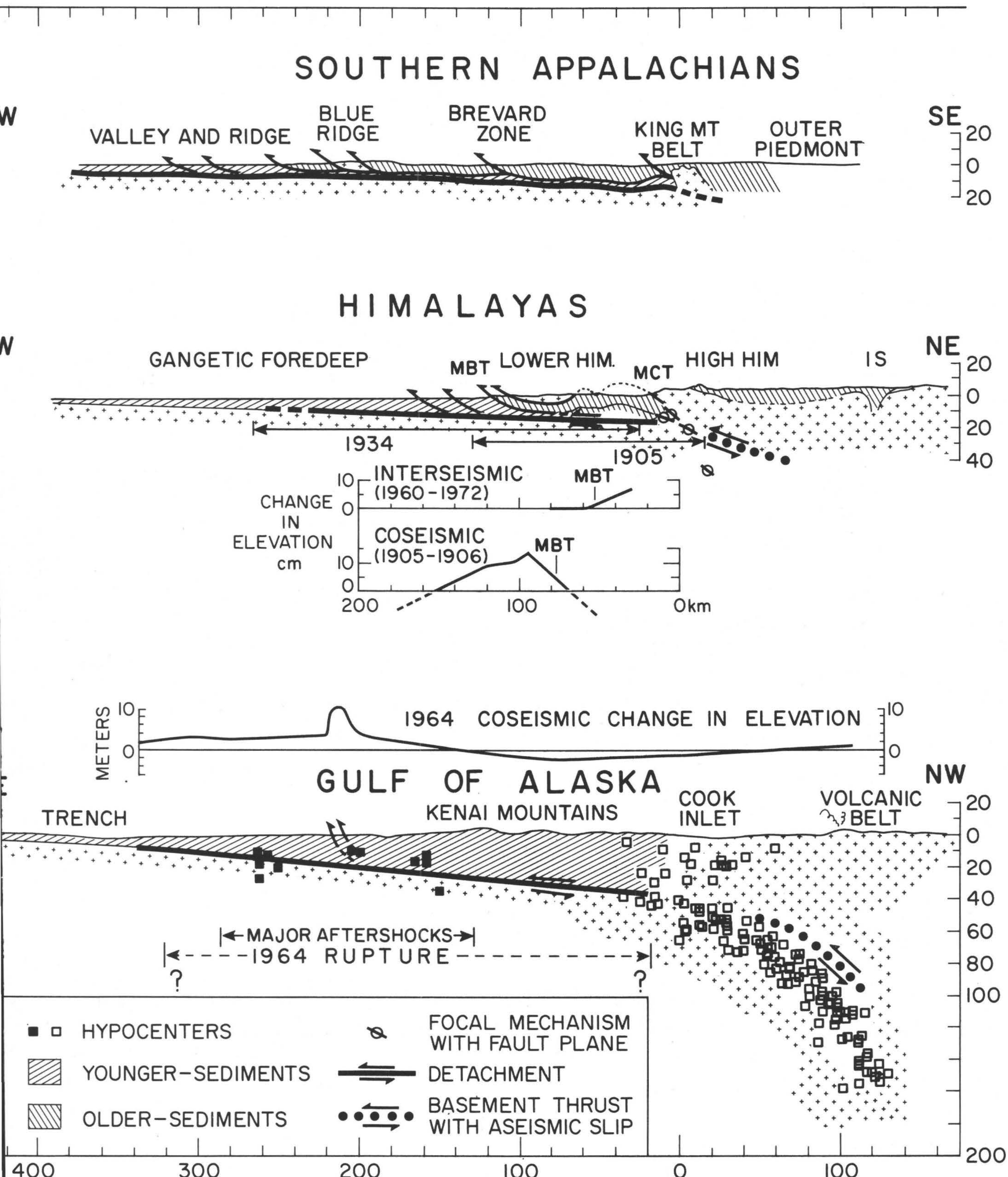

Figure 1. A comparison between the fossil continental collision of the southern Appalachians (Brown et al., 1979), the central Himalaya and the Gulf of Alaska (open symbols interseismic activity, Lahr et al., 1974; closed symbols aftershocks of the 1964 earthquake, Plafker, 1965). Note in each case the sedimentary wedge above a detachment and in the two active cases major earthquakes occur on the detachment while interseismic activity is at the down-dip end of the detachment where basement is in contact with basement.

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

14-08-0001-16725

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Investigations

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

2. Elastostatic modeling of stress fields in the Wasatch Front area for comparison with current microseismicity and geology, as well as for understanding the episodicity of surface faulting on the Wasatch fault.

3. Simultaneous inversion of local earthquake data for hypocenters and laterally-varying velocity structure.

4. Computation of seismic moment rates from geologic data for estimation of fault recurrence in the Utah region.

5. Systematic study of foreshock occurrence in the Utah region since 1850.

6. Analysis of data from two 50-km-long seismic refraction profiles across both active and quiescent earthquake zones within Salt Lake Valley.

7. Preliminary study of attenuation in the eastern Great Basin from intensity and ground-amplitude data.

8. Computation and analysis of ground-reponse spectra from the M_L 5.7 Logan (Cache Valley) earthquake of 1962.

Results

1. Quarterly bulletins for the Wasatch Front area for the period: January 1-June 30, 1979, include 369 earthquakes ($M_L \leq 3.6$). During this six-month report period, three earthquakes were felt. Earthquake sequences ($M_L \leq 3.3$) of two- to seven-days duration occurred: beneath the Newfoundland Mountains west of Great Salt Lake; north of Montpelier, Idaho; and near Santaquin, Utah.

*Final Tech. Rept. also includes contributions from: D. Doser, M. Griscom, B. Hawley, W. D. Richins, and G. Zandt.

2. A model consisting of a 20 km thick viscoelastic layer resting on a substratum that responds with bouyancy forces predicts adequately, but not necessarily uniquely, the observed pattern of microseismicity along the Wasatch Front. A broad linear zone of intense seismicity located parallel to, and a few tens of kilometers east of, the Wasatch fault is explained in terms of elastic bending stresses induced by crustal movement on the Wasatch fault. Maximum stresses are predicted 8 to 28 km east of the Wasatch fault with elastic bending stresses reaching 140-240 bars. Over periods of 10^5 yrs the crust must behave in a viscous manner in order to dissipate kilobars of stress, which would otherwise accumulate and lead to major faulting east of the Wasatch fault. This suggests a possible causal relationship between major faulting episodes on the Wasatch fault and flanking microseismicity.

3. An iterative inversion program has been developed that uses direct P- and S-wave arrival times to compute simultaneously three-dimensional velocity structure and hypocenters. Tests with synthetic data showed that solutions are unique and reasonably independent of model parameters. Application to real data from north-central Utah showed significant lateral variations in velocity exist along the Wasatch Front. However, the relocated epicenters were shifted an average of only 3 km from HYPOELLIPSE locations.

4. Data on age of offset, amount of offset, and fault lengths of active faults in Utah were used to calculate both seismic moment rates and recurrence intervals for earthquakes in different areas of Utah. A comparison of return periods with those calculated from seismicity show that those calculated from moment rates are longer than those predicted by seismicity with the exception of the Wasatch fault area. This discrepancy may be due to the fact that the return period from seismicity on the Wasatch fault was calculated with only ten years of modern seismic data (1968-1978). A moment-magnitude relationship for the Utah region is being developed to improve return period calculations based on moment rates.

5. A systematic study of foreshock occurrence in the Utah region since 1850 has been completed as part of an on-going study of space-time seismicity patterns. Defining a foreshock to be any event within 40 days and 50 km of a mainshock, 16% (16 out of 99) of all historical mainshocks $\geq$ M.M.IV, and 43% (18 out of 42) of all instrumental mainshocks $\geq M_L$ 3.5 in the Utah region have been preceded by foreshocks. Foreshock occurrence does not correlate with definable geographic regions. During the 100 days preceding a main event, changes in seismicity are not generally evident until the last 10 days before the main event.

6. From two seismic refraction profiles observed N-S and E-W across the Salt Lake Valley, a Pg refractor velocity of 6.0 km/sec was determined for a line recorded north of the Bingham mine to the Great Salt Lake. On a line to the east that extended across the Salt Lake Valley and across the Wasatch fault at Little Cottonwood Canyon, the Pg-refractor velocity varies significantly across the valley portion indicating significant lateral velocity variation, but returns to a normal 6.0 km/sec on the east side of the Wasatch fault. Shear waves were well recorded on the north-line from

which a V_p/V_s ratio of 1.64 ± .02 was determined. Well developed shear energy was also recorded on the east line up to the Wasatch fault, but the S-waves appear severely attenuated east of the fault zone. Analyses of the S-wave attenuation are being made to model the width and effect of the fault zone in S-wave propogation.

7. Regionalized attenuation studies of both intensity and ground amplitude (as measured on Wood-Anderson seismograms) indicate that the eastern margin of the Great Basin, that is characterized by thin crust (~25 km) and low Pn velocity (~7.5 km/sec), exhibits seismic attenuation greater than that in neighboring areas and comparable to that in California. The assumption that attenuation throughout the Intermountain area is intermediate between that in California and the eastern U.S. appears invalid for the Wasatch Front area.

8. Response and Fourier spectra have been computed from accelerograms of the M_L 5.7 Logan, Utah, earthquake of 1962 using the methodology of Trifunac and Lee (1978). The three-component accelerograms and corresponding spectra represent the only set available for the entire Utah region.

Reports and Publications

Arabasz, W. J., Smith, R. B., and Richins, W. D., eds., 1979, Earthquake Studies in Utah, 1850 to 1978: Salt Lake City, University of Utah, 552 p.

Above-cited volume includes following manuscripts, completed under this contract:

1) Arabasz, W. J., Smith, R. B., and Richins, W. D., 1979, Earthquake studies along the Wasatch Front, Utah: Network monitoring, seismicity and seismic hazards, p. 253-285.*

2) Smith, R. B., Zandt, G., and J. E. Gaiser, 1979, A feasibility study of earthquake prediction using temporal variations in seismic velocity along the Wasatch Front from quarry-blast monitoring, p. 278-319.

3) Pavlis, T. L., 1979, Slip vectors on faults near Salt Lake City from Quaternary displacements and seismicity, p. 375-381.

4) Griscom, M., and Arabasz, W. J., 1979, Local magnitude (M_L) in the Wasatch Front and Utah region: Wood-Anderson calibration, coda-duration estimates of M_L, and M_L versus m_b, p. 433-443.

5) Cook, K. L., 1979, Effects of the earthquakes in the Magna area, Salt Lake County, Utah, during February-March 1978, p. 475-485.

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*Included in Proc. of USGS Conference on Earthquake Hazards Along the Wasatch Front and in the Reno-Carson City Area (and also being submitted to Bull. Seism. Soc. Am.).

6) Smith, R. B., and Lehman, J. A., 1979, Ground response spectra from the M_L 5.7 Logan, (Cache Valley) earthquake of 1962, p. 487-495.

Zandt, G., 1979, Crustal flexure and earthquake-generating stress along the Wasatch Front, Utah: U.S. Geological Survey Proc. of Conference on Earthquake Hazards Along the Wasatch Front and in the Reno-Carson City Area.*

Hawley, B. W., 1979, Simultaneous inversion of local earthquake data for hypocenters and laterally-varying velocity structure: University of Utah, M.S. Thesis.

*Included in Proc. of U.S.G.S. Conference on Earthquake Hazards Along the Wasatch Front and in the Reno-Carson City Area (and also being submitted to Bull. Seism. Soc. Am.).

Earthquake Hazard Studies in Southeast Missouri

14-08-0001-16708

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Investigations

1. Analysis of earthquake data from the 16-station New Madrid array.

2. Analysis of microearthquakes recorded by a portable array near Ridgely, Tennessee.

3. Interfacing present array operations with the installation of additional stations in the central Mississippi Valley.

4. Surface wave focal mechanism studies of eastern U.S. earthquakes, including the January 23, 1966 Dulce, NM and the 1967 Denver, CO earthquakes.

Results

1. The quarterly bulletin for the central Mississippu Valley (April 1, 1979 - June 30, 1979) includes 52 earthquakes. Figure 1 shows the locations of 244 earthquakes located during the year 1978 as a function of their focal depths.

2. Ninety microearthquakes were located near Ridgely, TN by a microearthquake survey conducted from May 10 to June 11, 1978. The diffuse seismicity pattern near Ridgely is now known to be due to earthquakes on a fault dipping to the southwest. Composite focal mechanisms indicate reverse faulting along a northwest striking fault plane. The first vertical depth profile in the midwest, Figure 2, shows the projection of epicenters along a plane striking N50°E. The southwestwardly dipping fault plane is quite apparent.

3. A computer program FASTHYPO was developed for fast interactive location of earthquakes. This program is running on two different computers and provides a quick location for use when a local earthquake generates interest in the news media. This program is also used in conjunction with seismogram viewing by giving an immediate check of the correctness of a reading while the readings are made. Final epicenter determinations are still being made with HYPO71.

4. A significantly new method for the determination of shear wave Q was developed by starting with the Aki (1969) coda paper. The method requires only readings of peak frequency as a function of time after the earthquake origin time and a fit of these readings to a master curve depending only on the seismograph instrument response used. The Nuttli Q estimates based on the spatial attenuation of the L_g wave are found to be valid.

5. The Dulce, New Mexico earthquake of January 23, 1966 had a focal depth of 3 km and was due to normal faulting along a north-south striking fault. The accuracy of the solution is shown by a very good fit of the complete theoretical time histories (P through surface waves) with the observed long period seismograms at ALQ and GOL. The focal mechanism is well constrained by the surface wave spectral amplitudes and waveform match.

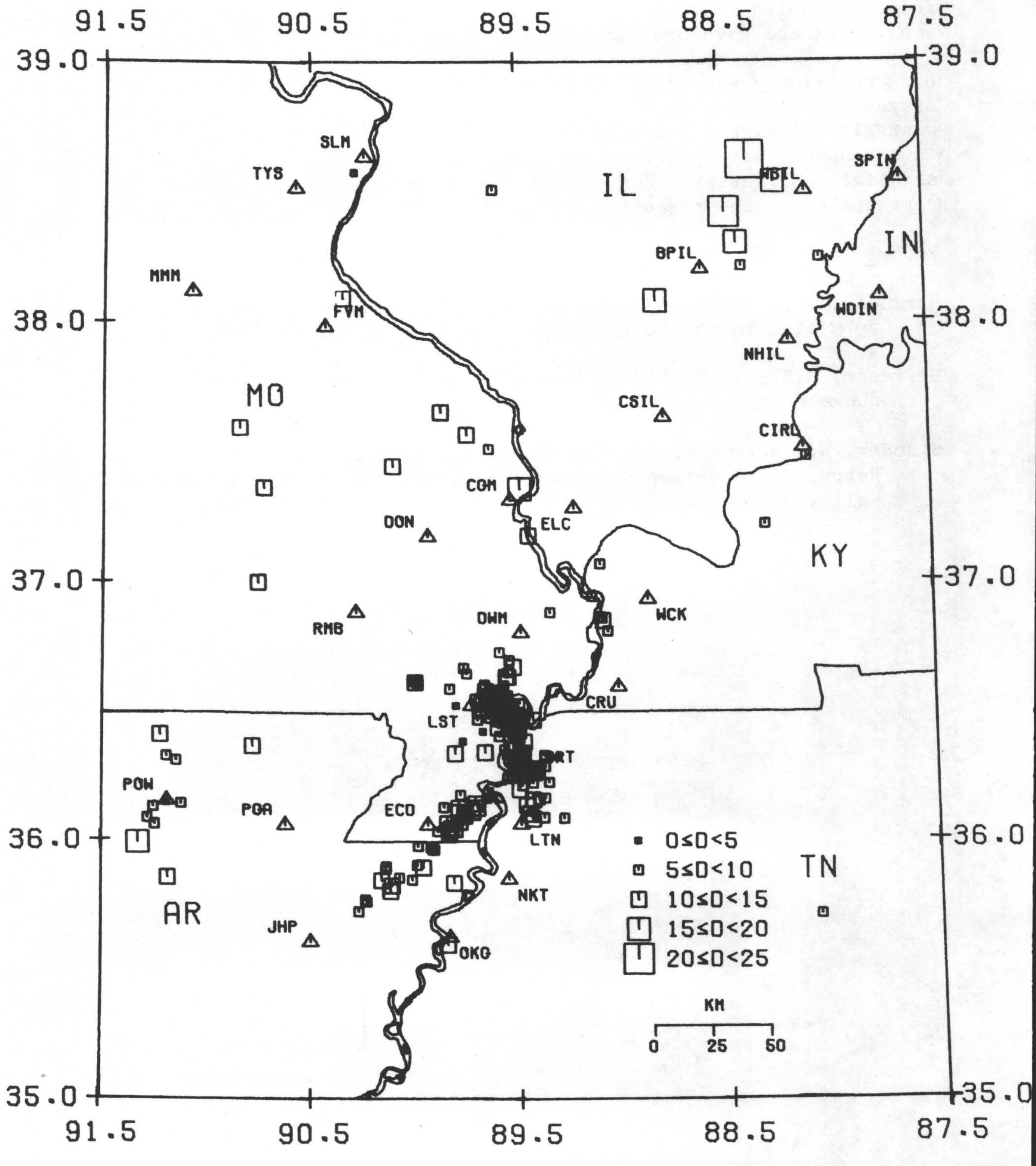
6. Preliminary surface wave analysis of two of the Rocky Mountain Arsenal earthquakes in 1967 indicate shallow focal depths and north-westerly striking dip-slip faulting. The focal depth and strike are in consonance with previous work, but the focal mechanism is substantially different. Further work on these presumably induced earthquakes is in progress.

Reports and Publications

Herrmann, R.B., 1980, Q estimates using the coda of local earthquakes: submitted to the Bull. Seism. Soc. Am.

Herrmann, R.B., 1979, FASTHYPO--A hypocenter location program: Earthquake Notes, in press.

Stauder, W., Herrmann, R., Nicholson, C., Singh, S., Woods, M., Kim, C., Perry, R., Morrissey, S., and Haug, E., 1980, Central Mississippi Valley earthquakes - 1978: submitted to Earthquake Notes.

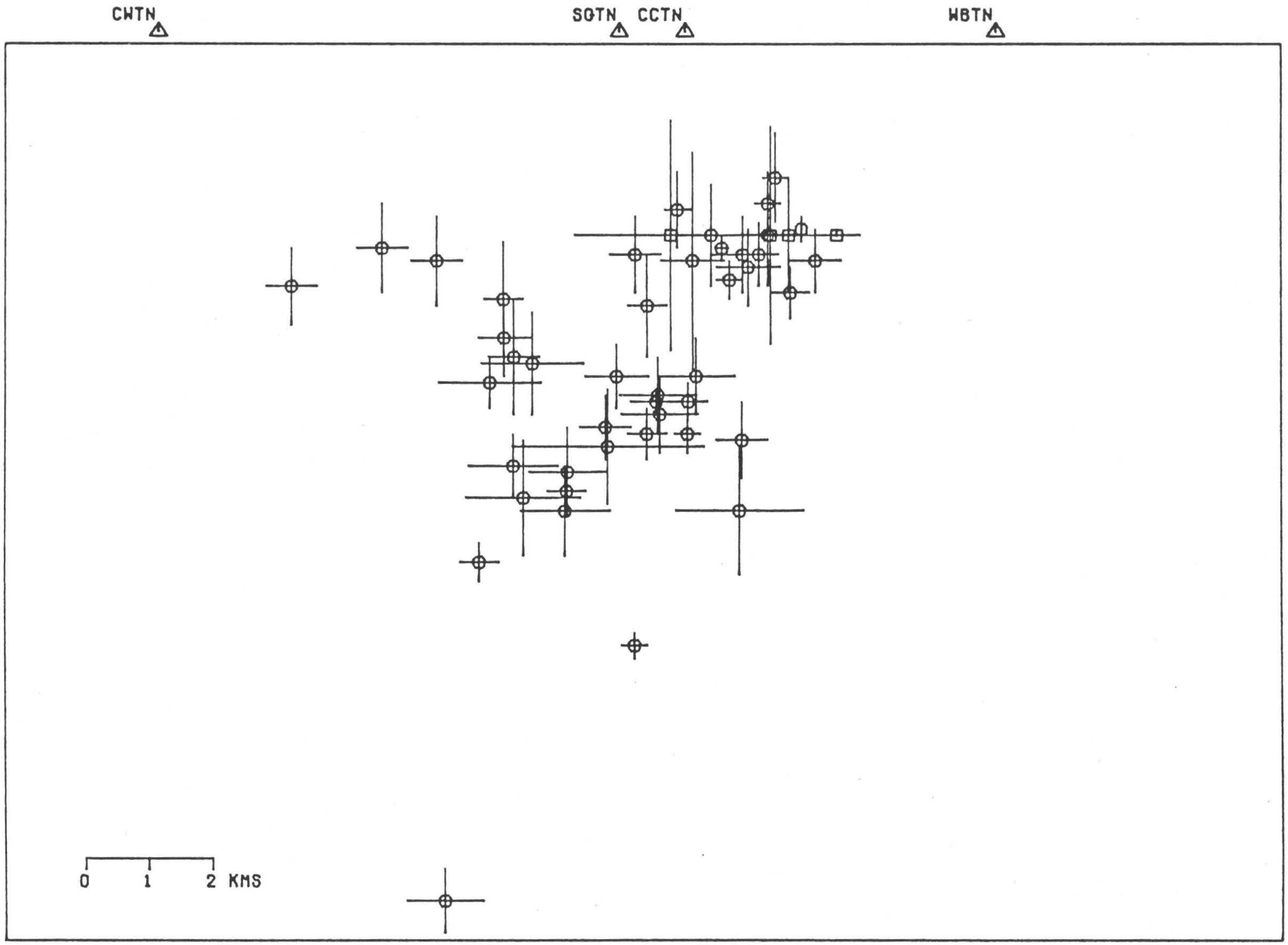


1978

CUMULATIVE EVENTS 01 JAN 1978 TO 31 DEC 1978

LEGEND . △ STATION ▫ EPICENTER

Figure 1



VERTICAL PROFILE CENTERED AT 36.265° N, 89.470° W
WITH STRIKE 50°

Figure 2

G.A.

Earthquake Data-Base Studies

9950-02092

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Investigations

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

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

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

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

Results

The design of the U.S. Earthquake Data-Base (USEQDB) was completed during this report period. In addition, two independent data-base management systems (DBMS) for interfacing with the data-base on the Multics computer were completed. The first of these is the Earthquake Record Management System (ERMS) DBMS which is rapid and efficient to use for simple retrievals because it uses keyed records of fixed length. ERMS files and ERMS software are used in editing new catalogs and entering them into the data-base. The second system is the MRDS DBMS which uses the MRDS relational data-base management sub-language. It is intended for research-oriented projects which require extracting customized subsets of data from a large data-base.

The ERMS DBMS is operational in the sense that other in-house projects are using it to extract earthquake catalog data from the data-base (table 1). The MRDS DBMS is not currently operational as it is a prototype implementation that was designed to test the relational data-base management philosophy.

Catalogs that are as accurate and comprehensive as possible are essential for any evaluation of theoretical seismicity models for the United States, particularly as those models are limited by incompleteness. The compilation of a complete southeastern U.S. catalog, using ERMS software, was a major accomplishment this report period. All existing compilations of regional, state, network, and special catalogs were merged, duplicates were removed, and entries were corrected for conflicts (intensity and origin time were the most common).

Table 1

Table of earthquake catalogs in the U.S. Earthquake Data-Base

REGIONAL CATALOGS

Name	Catalog	Compilers
EUSEQ	Eastern U.S. earthquakes, 1534-1977	Various
GAB75	Southeastern U.S. earthquakes, 1698-1974	Bollinger
NECAR	Northeastern Caribbean earthquakes	EDS
NEUSQ	Northeastern U.S. earthquakes	Chiburis
OWN79	Central U.S. earthquakes	Nuttli
SEUSN	Southeastern U.S. seismic networks, 1977-1979	Bollinger
SEUSQ	Southeastern U.S. earthquakes, 1698-1978	Tarr

STATE CATALOGS

Name	Catalog	Compilers
ALEDF	Alaskan earthquakes	EDS
GABVA	Virginia, 1974-1977	Bollinger
GABTR	South Carolina earthquakes prior to 1886	Bollinger and Visvanathan
SCEQS	South Carolina earthquakes, 1698-1978	Tarr and others
USQAL	Alabama earthquakes	Stover and others
USQAR	Arkansas earthquakes	"
USQFL	Florida earthquakes	"
USQGA	Georgia earthquakes	"
USQIL	Illinois earthquakes	"
USQIN	Indiana earthquakes	"
USQKY	Kentucky earthquakes	"
USQLA	Louisiana earthquakes	"

Table 1--Continued

STATE CATALOGS--Continued

USQME	Maine earthquakes	Stover and others
USQMO	Missouri earthquakes	"
USQMS	Mississippi earthquakes	"
USQOH	Ohio earthquakes	"
USQTN	Tennessee earthquakes	"

SEISMIC NETWORK CATALOGS

CMVNT	Central Mississippi Valley network, 1974-1979	Stauder and others
JOCSC	Lake Jocassee, S.C., network	Talwani and others
MONTN	Monticello Reservoir, S.C., network	Talwani and others
PRNET	Puerto Rico network	Dart and others
SCNET	South Carolina network	Rhea and others
SLMEQ	St. Louis University microearthquake study, 1978	Nicholson

SPECIAL CATALOGS

CHINA	Historical Chinese catalog	Lee
DEWEY	Relocated southeastern U.S. earthquakes	Dewey
GLBFM	Global focal mechanisms	Mauk and others
GWEQS	Great world earthquakes	EDS
ISSTR	In-situ stress measurements	Mauk and others
MCKEE	Bowman, SC earthquakes, 1972-1973	McKee
NAMFM	North American focal mechanisms	Mauk and others

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

Contract No. 14-08-0001-16704

UNIVERSITY OF SOUTHERN CALIFORNIA

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April 1, 1979 to September 30, 1979

Summary

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

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

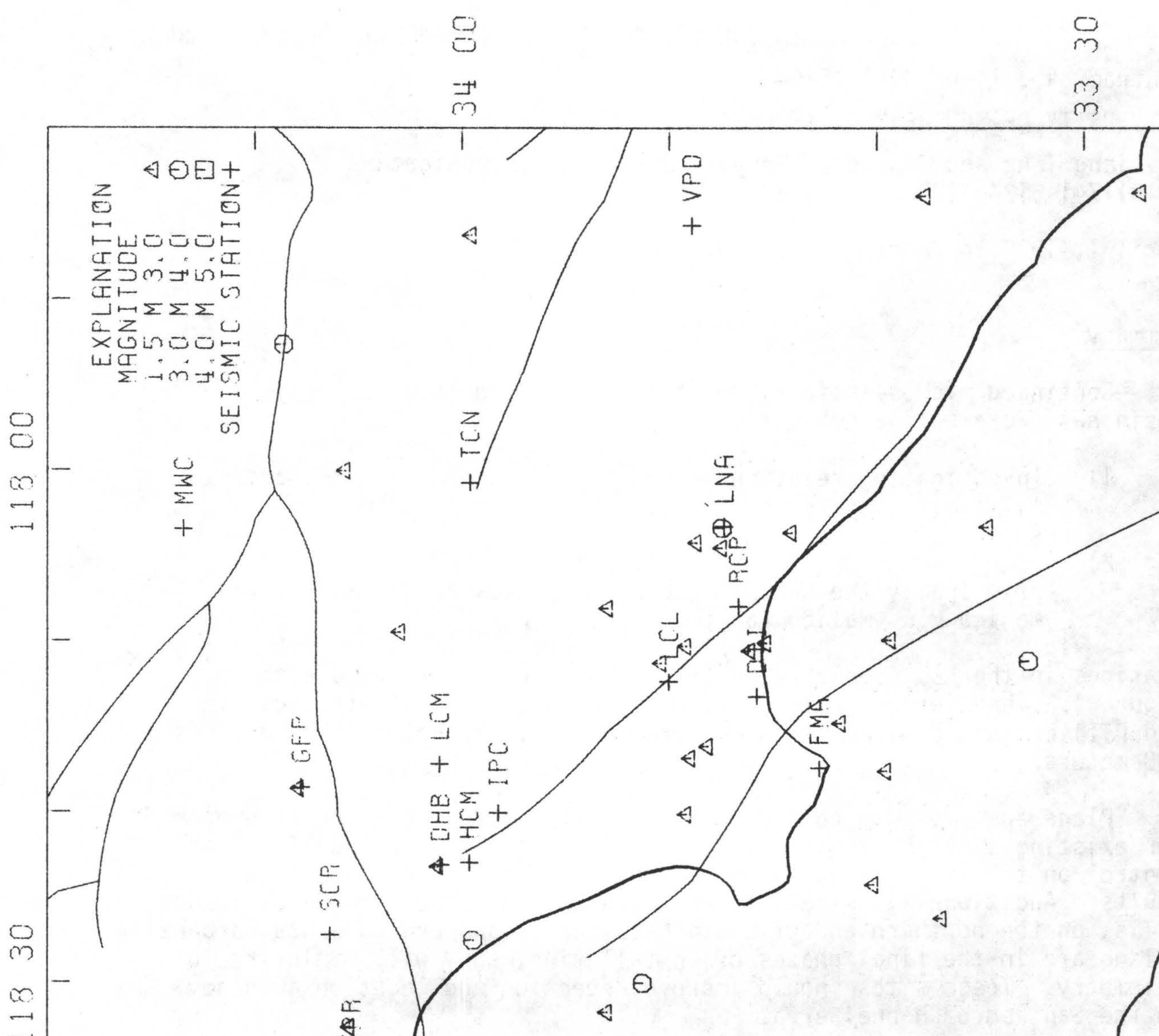
2) compiling earthquake statistics for coastal zone faults, principally the Newport-Inglewood, Palos Verdes and Santa Monica Mtns-Malibu faults.

Stations in the Los Angeles area presently being monitored are shown in figure 1. They include some Caltech/USGS stations. Two stations (DHB and DTI) contain downhole seismometers emplaced at depths in excess of 800 meters.

Plans are underway to add five new stations and to relocate one or two existing stations in the Baldwin Hills cluster to provide improved control on the Newport-Inglewood, Palos Verdes and Santa Monica-Malibu faults. Additionally, sites at the northwestern end of the Palos Verdes Hills, on the northern end of Santa Catalina Island and on Santa Barbara Island are in the final phases of installation; they will employ radio telemetry. These sites should improve detection and location accuracy in the San Pedro Channel area.

Seismicity of $M > 2$ in the greater Los Angeles area between April and September, 1979, is shown in figure 1. Aftershocks of the January 1, 1979 earthquake are conspicuous in Santa Monica Bay south of station TPR. Other, more diffuse activity appears in the southern basin and San Pedro Bay areas, probably associated with Newport-Inglewood and Palos Verdes fault trends.

A comprehensive seismo-tectonic analysis for the greater Los Angeles basin region has been completed and published as a USC Geophysical Laboratory Report.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118 30
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EXPLANATION
MAGNITUDE
1.5 M 3.0
3.0 M 4.0
4.0 M 5.0
SEISMIC STATION
MWC
TCN
VPD
GFP
SCR
TAR
DHB
LCM
HCM
IPC
CL
RCP
LNA
DAI
FMA
CIS

FIGURE 1

Field Experiment Operations

9970-01170

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Investigations

This project performs a broad range of management, maintenance, field operation, and record-keeping tasks in support of seismology and tectonophysics networks and field experiments. Seismic field systems that it maintains in a state of readiness and depoys and operates in the field (in cooperation with user projects) include:

a. 5-day-recorder portable seismic systems
b. Smoked paper-recorder portable seismic systems
c. "Centipede" portable microearthquake array
d. "Cassette" seismic refraction systems
e. Portable digital event recorders

This project also is responsible for obtaining the required permits from private landowners and public agencies for installation and operation of network sensors and for the conduct of a variety of field experiments including seismic refraction profiling, aftershock recording, teleseism P-delay studies, etc.

Results

Network augmentation. Permitting of sites and planning for telephone or radio telemetry has been completed for about 80 stations of the planned 150-station augmentation of the California seismic networks.

Seismic refraction. Project personnel carried out the permitting, drill-hole monitoring, loading, and firing of about 10 shots at 6 shot points during refraction experiments in Imperial Valley (California) during October 1979.

Portable networks. Current field programs are utilizing 15 five-day-recorder seismic systems in Arizona and 5 digital event recorders in southern California with maintenance and operation support from project personnel.

Earthquake Data Processing

9900-90034

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Investigations

Perhaps the single greatest problem facing the earthquake program is our inability to process adequately and in a timely manner the increasingly large volume of data we collect. Where available, the data are a long way from being directly usable in any particular geophysical investigation; and the common tasks of access, organization, and routine display are left up to the individual scientist to carry out. Not only have tens of thousands of hours of researchers' time been diverted into duplicated programing efforts, but these programs are seldom flexible enough even to remain in constant use for that researcher, and rarely serve other projects' needs. The problem, therefore, is to facilitate publication of research papers and earthquake bulletins by organizing the data and associated analysis tools into a general computer environment thus freeing the researcher to focus on the specific geophysical problems. As future research yields additional analysis tools, these too can be easily included in the common repertoire for the benefit of all future investigators.

Objectives

We are in the process of assembling a computer environment aimed at facilitating access to geophysical data directly and through a wide variety of easily programable, interactive analysis tools. The primary objectives for the environment are as follows:

A. Routine analysis of large volumes of data: It must be easy to establish, run, and maintain methods for routine analysis of large volumes of data.

B. Data base services: The data must be organized so that retrieval of a desired subset of that data can be made without writing a special program.

C. High-level data organization: Data should be organized according to how scientists think about the data and according to its use in scientific applications, rather than in a way which is convenient for the particular machine design.

D. High level analysis tools: Scientists must be able to analyze the same data in a truly interactive mode where simple as well as complex tasks are performed easily and rapidly so that emphasis is on what should be done and why, rather than the nitty-gritty details of how.

E. "Hands on": A wide range of tools should be available for analysis but it should be easy to add new custom tools. Since scientists are inherently skeptical about tools developed by others, it must be easy to examine and rewrite existing tools.

F. Efficiency: In the trade-off between human labor and machine time, small tasks will want to favor the user's time and large production jobs will have to be settled in favor of machine optimization.

G. Exchange: It must be easy to exchange data and tools within the same organization and nationwide.

H. The users: The system must be easily understandable and of use to a wide variety of people ranging in experience from uninitiated clerks and technicians to thoroughly seasoned programmers and scientists.

I. Documentation: The system must be well-documented both in the form of manuals and on-line "help" aid.

J. Geolab is voluntary: The Geolab data analysis system will be available to users; however, it is anticipated that some applications will make little or no use of its services; accordingly, all of the normal facilities of the UNIX operating system must be available to users at all times including language compilers (Fortran, C, Pascal, etc.) and text editors. Furthermore, most of the major Geolab tools must be callable from other programing languages and environments.

K. Cost: The cost in terms of dollars and labor must be kept low.

Strategy:

We have a three-part strategy for building the necessary data analysis environment--an environment which must be flexible and agile in the face of rapidly changing needs.

First, the data are organized in databases which, although widely varying in content, will all share the same form and hence most of the same software. Instead of storing information in card-image form where the actual organization is often shaped by 80-column squeezing considerations, we organize the data "the way we think about it"--in categories supported by a database system.

Secondly, rather than planning large stand-alone programs corresponding to each phase of work, we are developing a large number of small tools, each standing as a single functional unit. These tools can be combined and recombined into larger units. By sharing such tools, there is little need to develop a new program from scratch. The human labor is significantly reduced and available energy can be focused on crafting any new tools that may be needed. Furthermore, when many tasks share the same general tools, a significant improvement in one tool becomes useful to many. Heavily used tools can be optimized for speed and may be available in various versions.

The third and very crucial part of our strategy is to deliver the data and associated analysis tools directly to the user. Our approach is to provide the Geolab interactive command language as the user's "window and hands" into the system. Far from providing a fixed set of predefined options so often found in analysis packages, Geolab is a complete language. Its purpose is to serve as a sort of "control panel" giving the user instant access to and use of the above mentioned data bases and common tools. Perhaps even more important, Geolab provides an arena wherein new tools can be added in seconds. Geolab is fully extensible and is just as useful for maintaining fiscal records as it is for analyzing tilt, seismic, or bibliographic data. The best part is that every time a line is typed on the computer terminal, it is executed; thus feedback is instantaneous and the computer becomes an extension of the user's thought process.

Results

Spring 1979: A completely new version of Geolab has been written aimed at high portability and improvement of a variety of features. A second version of Geobase has been written and is being tested on large volumes of a wide variety of data. The plotting package has been written as device independent and yet maximizing use of special device features to allow faster output. Many tools for filtering, smoothing, cross-correlations, fft, etc., exist and new tools have been written or adapted for picking P-wave arrivals, reading arbitrary time-codes, selecting data in any arbitrary three-dimensional polygonal space, and for locating earthquakes.

Summer, 1979: UNIX was installed and is being modified to allow real-time data acquisition, to run on the PDP 11-34, and to include a wide variety of features available from sources other than Bell Labs. The use of Geolab and Geobase for managing office fiscal accounts in FY80 is being investigated.

September-October 1979: Integration of UNIX, Geolab, Geobase, and Geoplot will be nearing completion. At this stage we hope to involve more scientists in Menlo and from the universities in reviewing and adding to the software and in beginning to analyze data. Training sessions will be held and manuals printed.

November-December 1979: Work out most of the major problems in the software and begin use of the system for large scale routine analysis.

Winter 1980: Complete documentation. Facilitate transferral of a wide variety of tasks to this system. Facilitate documentation and exchange of user-developed tools.

Spring 1980: Integrate the analysis system into real-time data collection and on-line analysis efforts on the 11-34, the strain projects 11-03, and Rex Allen's microprocessors and Sam Stewart's data collection system.

SEISMIC RISK IN THE ASSAM GAP

Contract No. 14-08-0001-16841

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The seismicity data from 1825 to the present for the Assam (northeastern India) region show that seismicity rates there deviate from normal before and after major earthquakes. Along this 1,000-km-long section of a plate boundary, all shocks with magnitude $M > 6.6$ were preceded and sometimes followed by periods of significant seismic quiescence, and no such quiescence occurred at times other than before or after a major event. The most remarkable periods of quiescence lasted about 28 and 30 years before the two great ($M = 8.7$) Assam earthquakes of 1897 and 1950. Other periods of anomalously low seismicity preceded main shocks of magnitudes 6.7 (in 1950 and 1975), 7.8 (in 1869), and 7.7 (in 1947), with durations of 6, 8, 23, and 17 years, respectively. These durations fit (with approximately the scatter of the original data) a published relation between precursor time and magnitude.

Since these changes of seismicity rate were observed at the edges of and within the Assam gap, defined by the 1897 and 1950 great earthquakes, it is likely that a future major or great earthquake in this gap will be preceded by seismic quiescence. Whether a preparatory phase for an earthquake has begun in the Assam gap cannot be stated for certain because of the changing earthquake-detection capability in the area and because of poor location accuracy.

As a result of the above-mentioned observations, a cooperative program to study the Assam Gap is developing. Leveling lines, gravity profiles, magnetic surveys, seismological and strong motion studies are planned. Some of the Indian institutions participating are Roorkee University, Indian Geodetic Survey, Indian Geological Survey, Indian Meteorological Department, National Geophysical Research Institute, and School of Earthquake Engineering of Roorkee.

Field conditions have been checked and field support is organized. Permission for import of seismographs has not been granted yet.

Seismic Studies of Fault Mechanics

9930-02103

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Investigations

1. An interactive computer processing system for standard California network seismic data is being implemented on the Eclipse computer system.

2. Mantle structure beneath central California is being studied using three-dimensional velocity modeling techniques.

3. Crustal structure along active faults in central California is being studied.

4. Microearthquake occurrence patterns and their relationship to active faults is being studied.

Results

1. A system for interactive and semiautomatic processing of California network FM telemetry tapes has been developed for the Eclipse computer system in Menlo Park. This work is being done in cooperation with the Minicomputer System Development project (9970-02118) and the Coherent Waveform Analysis project (9930-02296). We are currently undergoing a final system shake-down and are training analysists from the California Network Analysis group, who will use the system for routine earthquake catalog processing and bulletin preparation. A modified version of R. V. Allen's p-picker is proving to be an extremely successful tool for routine measurement of earthquake onset times.

2. Three-dimensional structure beneath central California from Fresno to Red Bluff, California and from the Pacific Ocean to the crest of the Sierra Nevada is being imaged to depths in excess of 250 km. Strong lateral variations are found at all depth levels in the model. The pattern of relative velocity fluctuations shows a strong NW-SE trend in the lithosphere (0-75 km) and below

125 km. Vertical velocity gradients are much steeper beneath coastal California than beneath the Sierran Foothills province.

3. Preliminary results from regional scale crustal structure studies along the San Andres fault near Mustang Ridge and the Calaveras fault near Coyote Lake indicates that these two areas are underlain by markedly different crustal sections. Crustal velocities are substantially higher along the Coyote Lake segment of the Calaveras fault where intermediate velocity material may be present at depths of 5-10 km. Along the creep-active segment of the San Andreas fault near Mustang Ridge, structural models reflect the juxtaposition of dissimilar crustal sections.

4. Microearthquake clustering patterns along a 45 km segment of the Calaveras fault centered on the 15-km-long aftershock zone of the M_L 5.9 earthquake of 6 August 1979 was examined for the 10-year period prior to the event. Microearthquake clusters were observed to be preferentially concentrated near the end of the aftershock zone. The clustering process appears to have been stable during the 10-year period, and no distinct changes either in space or time were noted before the 6 August earthquake. These results suggest that the fault has distinct, long-term mechanical properties revealed by microearthquake occurrence patterns.

Reports

Cockerham, R., and Ellsworth, W. L., 1979, Three-dimensional large-scale mantle structure in central california (abs.): EOS, American Geophysical Union Transactions (in press).

Savage, W. U., and Ellsworth, W. L., 1979, Microearthquake clustering preceding the Coyote Lake earthquake (abs.): EOS, American Geophysical Union Transactions (in press).

Mantis, C., 1979, PARTIAL ECLIPSE, A manual for the ECLIPSE earthquake processing system: Administrative report, 69 p.

DEVIATORIC STRESSES IN THE EARTH'S CRUST AND UPPERMOST MANTLE

9960-02414

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The Problem

The magnitude of deviatoric stresses in the Earth's crust and uppermost mantle, and especially the magnitude of shear stresses that resist plate motions across the major plate boundaries, is a matter of central importance to solid-earth geophysics. Since currently available estimates of them vary by at least a factor of 10 - and closer to 100 in some interpretations- such fundamental issues as the driving mechanism(s) of plate tectonics and the energetics of crustal faulting are entirely unresolved. More generally, there is very little in the study of active geologic processes of geophysical interest that does not involve material deformation of some kind or another; in understated terms, the analysis of material deformation to reveal causative processes is poorly constrained when the magnitude of the deviatoric stresses involved is so uncertain.

The Happenings

This project supported investigations of the magnitude of deviatoric stresses accompanying the outer rise deformation. The character and timing of frictional heating along the Alpine fault (New Zealand), and the strength of the Earth's crust and uppermost mantle is inferred from gravity and topography observations (see publications below). In addition, a conference on Magnitude of Deviatoric Stress in the Earth's Crust and Uppermost Mantle was organized and convened during the funding period. Thirty-two participants contributed a written paper to it; these will appear as Proceedings of Conference IX..., the standard red book format issuing from Jack Evernden's office. A special issue of Journal of Geophysical Research will also be forthcoming.

The Results

To the question of whether the magnitudes of deviatoric stresses across the upper several tens of kilometers that are the Earth's crust and uppermost mantle is a kilobar (or somewhat greater) or 100 bars (or perhaps somewhat less), answers of the sort yes, maybe, and sometimes seem the most appropriate. This ambiguity certainly stems, at least in part, from our ignorance of how the Earth really works; more importantly, however, it may sensibly reflect the great diversity in scale, time, and form of the geologic processes that shape the face of the Earth. If there is a single essential thread to this fabric of diversity, it is likely to be the mechanical, chemical, and thermodynamic characteristics of water under conditions appropriate to the crust and uppermost mantle.

The Publications

Hanks, T. C., 1979, Deviatoric stresses and earthquake occurrence at the outer rise, J. Geophys. Res., 84, 2343-2347.

Scholz, C. H., J. Beavan, and T. C. Hanks, 1979, Frictional metamorphism argon depletion, and tectonic stress on the Alpine fault, New Zealand, J. Geophys. Res., in press.

McNutt, M. K., and R. L. Parker, 1979, Implications of global activity for state of stress in the Earth's crust and upper mantle, Proceedings of Conference IX..., in press.

Hanks, T. C., 1979, Crustal earthquake stress drops, Proceedings of Conference IX..., in press.

Proceedings of Conference IX, Magnitude of Deviatoric Stresses in the Earth's Crust and Uppermost Mantle (30 papers, approximately 1000 pages)., T. C. Hanks and C. B. Raleigh: organizers.

Hanks, T. C., and C. B. Raleigh, The conference on magnitude of deviatoric stresses in the Earth's crust and uppermost mantle, preface to the special issue of J. Geophys. Res.

Fault Zone Structure
9960-01725

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Mt. Hood, Oregon

A seismic refraction system utilizing 100 portable recorders was used to study crustal structure and anisotropy in the Mt. Hood, Oregon, region. Recordings were made at 200 locations from 10 explosions at 6 shot points, all within an area of 250 km^2. A time term method was used to reduce the data; the results show three refractors with a velocity of 5.0, 6.0, and 6.6 km/s. The time terms reveal a region of large seismic delay associated with the main edifice of Mt. Hood. The mountain is surrounded by a region of smaller time terms or higher velocity in a pattern that suggests a genetic relationship between this feature and Mt. Hood. A pronounced anisotropy is associated with the 5.0 and 6.0 km/s refractors. The 6.6 km/s refractor does not appear to be anisotropic. The regional north-south direction of the maximum velocity correlates with the regional stress deduced from fault plane solutions. This, coupled with the disappearance of anisotropy with depth, strongly suggests that the anisotropy is caused by the behavior of cracks in the current stress field.

Imperial Valley, California

An extensive seismic refraction investigation of the central Imperial Valley, southern California, was conducted in early 1979 to study the geological and velocity structure of this important tectonic province. Forty shots fired at seven separate locations were recorded by the 100 portable recorders, yielding over 3600 useable seismograms; these profiles cover an area $\sim$8500 km^2. Digital record sections were produced in the field using a portable computer and plotter. Contour maps of travel time delays with respect to a refractor velocity of 6 km/s show a deep northwest trending trough having a maximum delay of 1.8 s coinciding approximately with the zone of maximum seismicity. Prominent scarps are seen along the Coyote Creek branch of the San Jacinto fault and the Laguna Salada branch of the Elsinore fault, and a prominent hole (1.8 s maximum delay) is seen in the vicinity of Mesquite Lake. Seismograms show evidence of amplitude lost across major active faults as well as higher frequency transmissions through geothermal areas.

The observed velocity structure of the valley ranges from as low as 1.3-2.0 km/s, with thicknesses from 0.2 to 0.8 km, near the surface to 4.3-4.6 km/s above the basement rocks, with a thickness ranging from 1.5 to 2.5 km. Basement velocity is difficult to determine because of the lateral velocity variations in the overlying sediments and the apparently irregular basement topography. The best determinations were derived from three reversed profiles yielding velocities of 5.79 km/s, 5.66 km/s, and 5.88 km/s. For these central valley profiles, higher apparent velocities are observed for propagation toward the northwest than toward the southeast. This may indicate a general down-dip of basement to the southeast.

Coyote Lake Earthquake, California

The recent Coyote Lake earthquake near Gilroy, California, provided data to study the aftershock sequence in the vicinity of the San Andreas Fault Zone. About 60 cassette recorders, normally used for the refraction profiling, were deployed over the aftershock zone and operated long enough to capture a few aftershocks which are used to calibrate local travel times and determine station corrections. These data are then used to determine the location of the main shock and some of the larger aftershocks. At this time, there is not sufficient information about the velocity structure to assess the accuracy of the earthquake locations in central California.

Snake River Plain/Yellowstone

A seismic refraction profiling experiment was conducted in the Snake River Plain-Yellowstone Park area during the fall of 1978. The data has been processed for analog and digital playback and was sent to Robert Smith, coordinator of the experiment, at the University of Utah. A master data tape and composite record sections were generated and were made available in early November 1979.

Saudi Arabia

A seismic refraction profile was conducted across the Arabian Shield in western Saudi Arabia in February 1978 to study crustal and upper mantle velocities and seismic attenuation. All the data have been reduced and the records have been reproduced in a two-volume set presenting the locations, shot times, and seismograms. This data set will be used for the IASPEI Commission on Controlled Sourse Seismology workshop in Teton, Wyoming, in August 1980.

Reports

Braile, L. W., Smith, R. B., Ansorge, J., Baker, M. R., Prodehl, C., Healy, J. H., Mueller, St., Olsen, K. H., Priestly, K., Brune, J., 1979, The Yellowstone-Snake River Plain seismic profiling experiment: eastern Snake River Plain, American Geophysical Union Fall Meeting, San Francisco, December 1979.

Fuis, G. S., Mooney, W., and Healy, J. H., 1979, A seismic refraction survey on the Imperial Valley, California: Seismological Society of America Meeting, Golden, Colorado, May 1979.

Healy, J. H., Kohler, W. M., and Wegener, S. S., 1979, Upper crustal structure of the Mt. Hood, Oregon, region as revealed by time term analysis: American Geophysical Union Fall Meeting, San Francisco, December 1979.

Kohler, W. M., Healy, J. H., and Wegener, S. S., 1979, Upper crustal structure of the Mt. Hood, Oregon, region as revealed by time term analysis: Seismological Society of America Meeting, Golden, Colorado, May 1979

Kohler, W. M., Healy J. H., and Wegener, S. S., 1979, Upper crustal structure of the Mt. Hood, Oregon, region as revealed by time term analysis: Pacific Northwest American Geophysical Union Meeting, Bend, Oregon, September 1979.

Kohler, W. M., Lamson, R. J., and Healy, J. H., 1979, A study of P-wave attenuation in the Arabian shield using spectral rates: American Geophysical Union Fall Meeting, San Francisco, December 1979.

Lamson, R. J. Blank, H. R., Mooney, W. D., and Healy, J. H., 1979, Seismic refraction observations across the oceanic-continental rift zone, southwest Saudi Arabia: American Geophysical Union Fall Meeting, San Francisco, December 1979.

Lutter, W. J., Mooney, W. D., Fuis, G. S., and Healy, J. H., 1979, Travel-time analysis of seismic refraction profiles in the Imperial Valley, California: Pacific Northwest American Geophysical Union, Bend, Oregon, September 1979.

Mooney, W. D., Lutter, W. J., Healy, J. H., and Fuis, G. S., 1979, Velocity depth structure in central Imperial Valley, California: American Geophysical Union Fall Meeting, San Francisco, December 1979.

Smith, R. B., Braile, L. W., Schilly, M. K., Ansorge, J., Prodehl, C., Healy, J. H., Pelton, J. R., Mueller, St., Greensfelder, R., and Olsen K. H., 1979, The Yellowstone-Snake River Plain seismic profiling experiment: Yellowstone: American Geophysical Union Fall Meeting, San Francisco, December 1979.

Wegener, S. S., Healy, J. H., and Mooney, W. D., 1979, A calibration event for the Coyote Lake earthquake: American Geophysical Union Fall Meeting, San Francisco, December 1979.

Wegener, S. S., Mooney, W. D., and Healy, J. H., 1979, A long-range seismic refraction study of the High Cascades, Oregon: Pacific Northwest American Geophysical Union Meeting, Bend, Oregon, September 1979.

Blank, H. R., Healy, J. H., Roller, J., Lamson, R., Fisher, F., McClearn, R., and Allen, S., 1979, Seismic refraction profile, Kingdom of Saudi Arabia, field operations, instrumentation, and initial results: U.S. Geological Survey, Saudi Arabian Mission Project Report 259, 49 pp.

Technical Report Summary

Project Title: Stress Analysis of a Deeply Eroded Analog of the San Andreas Fault

Contract Number: 14-08-0001-17772

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Detailed collections of quartz-bearing rocks have been made across several major shear zones, including the Ikertoq shear zone in western Greenland, the Mullen Creek - Nash Fork shear zone in Wyoming and the Idaho Springs - Ralston Buttes shear zone in Colorado. Rocks from these faults have been analyzed by optical and transmission electron microscopy. The paleo-differential stress level across the shear zones is determined by counting free dislocation densities and by measuring subgrain sizes in deformed quartz grains in gneisses and quartzites. Estimates of the relative amounts of strain in the quartzites can be made based on the aspect ratios of relict quartz grains. In cases where the stress is found to be independent of distance from the fault, as is apparently the situation along the Idaho Springs - Ralston Buttes shear zone, changes in the strain in the quartzite corresponds to a change in the strain rate. Increases in strain rate approaching the shear zone must correspond to an increase in temperature. Temperature profiles across the shear zone can be obtained by assuming a flow law for quartz.

Deformed quartzites from the Idaho Springs - Ralston Buttes shear zone have free dislocation densities of approximately 5 x $10^8 cm^{-2}$, corresponding to a differential stress of approximately 150 MPa. The Idaho Springs - Ralston Buttes shear zone consists of a number of small shear zones, up to several meters wide, in which the quartzite is completely recrystallized. Outside the regions of these shear zones elongated relict quartz grains are still present in the quartzite. The quartzites and quartzo-feldspathic gneisses from the Mullen Creek - Nash Fork shear zone show a trend in free dislocation densities. The highest dislocation densities, 10 to 13 x $10^8 cm^{-2}$, occur in samples collected at the margins of the shear zone. The lowest dislocation densities, 3 to 4 x $10^8 cm^{-2}$, occur near the center of the shear zone. This trend may indicate that the microstructure in samples from the center of the shear zone was annealed after the main plastic deformation event. The Ikertoq shear zone is significantly larger than the shear zones sampled in Colorado and Wyoming. It will take some time before we can complete our analyses of the samples collected across this shear zone. In our study of the rocks from the Ikertoq shear zone we will concentrate first on the microstructures in the numerous deformed dikes and veins.

To complement our field and microscopy studies of the microstructures of naturally deformed rocks, we have begun static annealing experiments on deformed quartzites. In samples annealed at >800°C for 1 hour the free dislocation densities were found to decrease from approximately $10 \times 10^8 cm^{-2}$ to $2.5 \times 10^8 cm^{-2}$. During annealing numerous low-angle tilt and twist boundaries develop in the quartz grains. We are continuing these experiments in order to compare laboratory annealed microstructures with microstructures in naturally annealed quartz-bearing rocks.

Publications:

Kohlstedt, D.L., Cooper, R.F., Weathers, M.S., and Bird, J.M., 1979, Paleostress analysis of deformation-induced microstructures: Moine thrust fault and Ikertoq shear zone: in Proceedings of Conference VIII, Analysis of Actual Fault Zones in Bedrock, USGS Open File Report 79-1239, 394-425.

Weathers, M.S., Bird, J.M., Cooper, R.F., and Kohlstedt, D.L., 1979, Microstructure and stress analysis of the Mullen Creek - Nash Fork shear zone, Wyoming: in Proceedings of Conference VIII, Analysis of Actual Fault Zones in Bedrock, USGS Open File Report 79-1239, 426-447.

Cooper, R.F., and Kohlstedt, D.L., 1979, Dislocation recovery in naturally deformed quartz: Trans. Amer. Geophys. U., 60, 370.

Weathers, M.S., Cooper, R.F., Pierson, D.D., Bird, J.M., and Kohlstedt, D.L., 1979, Microstructural deformation and stress analysis of a Precambrian shear zone: Trans. Amer. Geophys. U., 60, 384.

Investigation of Thermal Regime Across the San Jacinto Fault Contract No. 17714

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Summary

Preliminary results indicate the geothermal gradients increase toward the San Jacinto fault trace near Anza, southern California. On the northeastern side of the fault, the gradients are 17, 22, 25°C/km at 16, 7, and 0.5 km from the fault, respectively; while on the southwestern side, the gradients are respectively 27 and 11°/km at 1 and 20 km from the fault. The trend confirms previous study by Henyey and Wasserberg (1971).

The significance of the trend can be better evaluated after the conductivity measurements are completed and the effect of topography and climate are assessed. The influence of fault movement on heat flow will be estimated in the final report.

CENTRIFUGE MODELING OF EARTHQUAKES AIR-GUN SEISMIC VELOCITY AND ATTENUATION MEASUREMENTS IN THE SAN ANDREAS FAULT ZONE

9960-02413

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Investigations

1. Mechanical property testing of centrifuge modeling material.

2. Repeatibility and directivity tests of Bolt Associates PAR DHS-600B borehole air-gun.

3. Laboratory measurements and theoretical consideration of rock internal friction at seismic wave periods.

4. Reformulation and discussion of mechanical behavior of the velocity-dependent friction law proposed by Dieterich.

Results

1. Uniaxial compression tests were carried out on silica-linseed oil mixture samples suitable for centrifuge modeling of crustal earthquakes. Typical uniaxial compressive strength with the silica and linseed oil mixing ratio of 800 gm silica to 12 cm^3 linseed oil and a standard curing procedure is 20 bars.

2. Repeatibility and directivity tests of the Bolt Associates PAR DHS-600B borehole air-gun was carried out at the USGS Stone Canyon site in the San Andreas fault zone. The repeatibility test indicates this particular air-gun to be a highly stable seismic source. Although the directivity test was interrupted by the rupture of the test hole well casing bottom, preliminary results indicate a negligible azimuth dependence of the borehole air-gun, when fired in a cased hole. This directivity test will be completed in the next report period.

3. Harmonic distortion in the stress time function applied to rock specimen affects the measurement of rock internal friction in the seismic wave periods by the stress-strain hysteresis loop method. If neglected, the harmonic distortion can result in a misinterpretation of rock internal friction by 30%.

4. Dieterich (1979) proposed a velocity-dependent friction law which explains his experimental data for velocity controlled rock friction tests. This law,

however, is not formulated in a differential or integral form. Consequently problems arise when this law is applied to cases when the slip velocity varies continuously with time. A differential equation reformulation of the friction law is achieved for which the law proposed by Dieterich is a special solution. Two examples of solution, one for velocity controlled slider and the other for traction controlled rigid slider, are given for this differential equation formulation. It is found that there exists a dynamic friction coefficient μ_o, greater than the static friction μ_s, at which stable sliding is possible. When the ratio of the applied traction to the normal stress exceeds μ_o, unstable accelerating sliding results. When the ratio of the applied traction to the normal stress is less than μ_o but greater than μ_s, the result is a stable transient sliding.

Reference Cited

Dieterich, J. H., 1979, Modeling of rock friction. I. Experimental results and constitutive equations. J. Geophys Res., 84, p. 2161-2168.

Publications

Liu, H-P., and Peselnick, L., 1979, Mechanical hysteresis loops of an anelastic solid and the determination of rock attenuation properties: Geophys. Res. Letters, 6, 545-548.

Peselnick, L., Liu, H.-P., and Harper, K. R., 1979, Observation of details of hysteresis loops in Westerly granite: Geophys. Res. Letters, 7, 693-696.

THEORETICAL STUDIES OF THE ROLE OF PORE FLUID IN PREMONITORY PHENOMENA

Contract No. 16795

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SUMMARY

The main results from this study stem from an investigation of coupled deformation-fluid diffusion effects and their effect on the failure process for a fluid-infiltrated fissured rock mass. Predictions were based on the inclusion model of faulting introduced by Rudnicki (1977a). Specifically, this model considers the deformation of an unbouded rock mass containing an inclusion which is meant to idealize a fault zone and which undergoes inealstic strain softening behavior. Transient stabilization of incipient faulting, by diffusion of pore fluid was investigated using the solution of Rice *et al*. (1977), and the treatment of Rudnicki (1977b) was adopted to model dilatancy hardening. The influence of geometry of the weakened zone was investigated by comparing the predictions for a spherical geometry with those pertaining to a vanishingly thin failure zone.

In the case of a spherical weakened zone, the stabilizing effect of dilatant hardening is found to cause a much more pronounced period of accelerating inclusion strain (relative to the far field loading rate) than in the absence of pore fluid. In addition, such effects may be associated with a small amount of dilatancy. On the other hand, the decrease of pore fluid pressure from its ambient value appears to become large only for a short time prior to final instability. The model provides therefore little support for the concept of dilatancy induced changes in seismic wave velocities, although non linear fluid compressibility (which was not included) might give rise to faster pressure drop.

On the basis of this model, typical calculated precursor times on the order of hundreds of days are found for fault dimensions

1-5 km and diffusivities ranging from 0.1 to 1.0 m^2sec, under a tectonic loading rate of 1 bar/year. The precursor time increases with fault size, although not as length squared: because strain accelerates most rapidly near the end of the precursory period, the time scale over which observable effects take place is likely to be shorter. It was estimated that observable premonitory behavior might be confined to a few days before earthquakes. This portion of the research was performed in close collaboration with J. R. Rice (Brown University) (Rice and Rudnicki, 1979).

The other geometry which was investigated involves a very narrow failure zone, reduced for purposes of analysis to a planar fault of vanishing thickness. The appropriate constitutive law is then assumed to relate τ, the shear traction on the fault surface, to δ, the relative slip. Numerical calculations in this case were perofmed for a parabolic form of $\tau(\delta)$ and a constant far-field (tectonic) loading rate.

In opposition to the results obtained in the case of a spherical inclusion, the precursor time -- period of self-driven accelerating slip preceding dynamic failure -- is predicted to decrease with increasing fault dimensions, for geophysically reasonable parameters. In contrast, simple dimensional analysis leads to the frequently assumed result that precursor time should increase with diffusion time (of the form L^2/c where L is fault length and c is diffusivity). The discrepancy stems from the implicit introduction of another characteristic length through the constitutive law: the sliding distance required to bring τ from its peak value to a residual frictional level. This distance must be scaled by the fault length. This leads to a non-dimensional driving term which increases with L faster than L^2, and thus to a precursor time which decreases with increasing L (Rudnicki, 1979).

Asperities and irregularities of the fault surface will lead to a dilatation which may be coupled with the diffusion of pore fluid. As a simple model of this mechanism, an opening dislocation was considered. The solution of Rice and Cleary (1976) leads to the conclusion that the effective compressive stress (total stress minur pore fluid pressure) induced on the fault by the surrounding elastic, but fluid-infiltration is less for rapid dilatation than for slow dilatation. In other words, this time dependent stiffness effect is destabilizing. On the other hand, a competing effect, "dilatant hardening" is due to the tendency of pore pressure to drop on the fault plane in response to dilatation. If this decrease takes place faster than it can be alleviated by influx of fluid by diffusion, the effective compressive stress on the fault is increased and further frictional sliding or inelastic shearing will be exhibited. A very simple analysis, which assumes that dilatation causes an influx of pore fluid, suggests that dilatant hardening effect can be very strong for a narrow zone. The analysis does not, however, include effects of non-linear fluid compressibility which can become significant for large reductions in local pore fluid pressure.

Active Seismology in Fault Zones

9930-02102

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Investigations

1. Resolve details of the P- and S-wave velocity structure and anelasticity (Q) of the crust and upper mantle in the vicinity of active fault zones using state-of-the-art field and data processing methods of both refraction and reflection seismology.

2. Provide velocity models of the crust and upper mantle for accurate location of earthquake hypocenters with respect to faults and other significant structural or compositional boundaries within the crust.

3. Establish constraints on the stress state (through velocity anisotropy determinations), composition, pore pressure (through Vp/Vs rations) and temperature of rocks in the region of the fault zones using the velocity and Q models obtained from the controlled-source seismic experiments together with data from laboratory and _in situ_ (drill-hole) measurements of these properties.

Results

1. In early 1979 we conducted an extensive seismic refraction experiment in the Imperial Valley in southern California. One hundred portable seismographs recorded over 3600 useable seismograms from 39 shots at 7 separate shot locations. A detailed view of the velocity structure of this important tectonic province emerges from these data. Near-surface velocities are low, ranging from 1.3 to 2.0 km/sec; thicknesses range from 0.2 to 0.8 km/sec. Velocities in the next two layers range from 2.3 km/sec to 2.6 km/sec and from 3.3 km/sec to 3.6 km/sec. Both layers have thicknesses in the range of 0 to 1.5 km, with an average value of 1 km, the greatest thicknesses occurring in the central portion of the valley.

The next layer has velocities ranging from 4.3 km/sec to 4.6 km/sec and thickness in the range of 1.5 km to 2.5 km. Apparent velocities beneath the 4.3 km/sec layer range from 5.3 km/sec to 6.2 km/sec. It is possible that an intermediate layer of 5.3 to 5.5 km/sec (fractured basalt?) overlies a basement of 5.8 km/sec to 6.2 km/sec in parts of the valley.

2. An earthquake of magnitude 6.4 occurred in the Imperial Valley on October 15, 1979. The velocity models which we have developed have been used by our coworkers at the USGS to provide accurate locations of the aftershocks of these earthquakes.

3. A method for the calculation of ray amplitudes and traveltimes has been developed which has enabled us to construct synthetic seismograms for laterally inhomogeneous media. Comparisons with data indicate that this new method will bring us closer to realizing our research goals described above.

Reports

Fuis, G. S., Mooney, W. D., and Healy, J. H., 1978, A seismic refraction survey in the Imperial Valley, California (abs.): Earthquake Notes, v. 49, no. 4, p. 98.

Lutter, W. J., Mooney, W. D., Fuis, G. S., and Healy, J. H., 1979, Traveltime analysis of seismic refraction profiles in the Imperial Valley, California (abs.): EOS, American Geophysical Union Transactions, v. 60 (in press).

Mooney, W. D., and Eaton, J. P., 1978, Pn velocity variations in central California (abs.): Earthquake Notes, v. 49, no. 4, p. 100.

ROCKS UNDER GEOTHERMAL CONDITIONS

9960-01490

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Investigations

1. Development of apparatus for measuring internal friction of rocks at seismic frequencies.

2. Theoretical bounds of elastic moduli of polycrystals.

Results

1. The apparatus for measuring internal friction (Q^{-1}) of rocks directly from the stress-strain loops at seismic frequencies provided information for improving the performance of the apparatus and for making the necessary design modifications for operation at elevated pressure and temperature (3 kilobars at 400°C). The distortion observed in the stress-strain wave forms was determined to result from a non-linear response of the force transducer. The strain sensitivity of the apparatus was increased to about 5×10^{-8} using an electrode spacing of 0.001 inch. This increased strain sensitivity will provide Q^{-1} data in rocks as a function of strain in the fractional Hz frequency range. A pressure vessel for the proposed 3 kbar and 400°C internal friction measurements was ordered. Two reports on previous work on anelasticity were published.

2. Equations were derived for the effective elastic moduli of hexagonal, trigonal, and tetragonal polycrystals using the variational formulation of Hashin and Shtrikman. This work was done in collaboration with J. Peter Watt (California Institute of Technology, Seismological Lab., Pasadena, CA). A manuscript was submitted for publication.

Reports

Liu, H.-P., and Peselnick, L., 1979, Mechanical hysteresis loops of an anelastic solid and the determination of rock attenuation properties, Geophys. Res. Letters, v. 6, no. 7, 545-548.

Peselnick, L., Liu, H.-P., and Harper, K. R., Observations of details of Hysteresis Loops in Westerly granite, Geophys. Res. Letters, v. 6, no. 9, 693-696.

Watt, J. P., and Peselnick, L., Clarification of the Hashin-Shtrikman bounds on the effective elastic moduli of polycrystals with hexagonal, trigonal, and tetragonal symmetries, (submitted to J. Appl. Physics, Aug. 1978.)

MECHANICS OF GEOLOGIC STRUCTURES ASSOCIATED WITH FAULTING

9960-02112

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Investigations

1. Paul Segall and I are mapping several small regions (about 100 m wide) in granitic rocks exposed along Bear Creek in the Mt. Abbott Quad, Sierra Nevada, California. Strike-slip faults cut these exposures with 0 to 10 m of shear displacement and examples of echelon offsets, secondary fractures, terminal splay cracks, and kink bands are abundant. These secondary structures are used to identify the processes involved in formation and growth of faults. Data and concepts derived from the field world serve to motivate and check theoretical studies of fault mechanics. We are using linear elasticity and fracture mechanics to study aspects of faulting, particularly the effects of fault geometry on the inhomogeneous loading of faults and on the deformation of surrounding rock. Although these investigations focus on a particular style of faulting in one small region, we are attempting to generalize our results where possible, to large strike-slip faults like the San Andreas, and to small faults in laboratory specimens of granite loaded to failure.

Results

The following abstract contains some generalizations about the effects of fault geometry on deformation and seismicity that have been drawn from our field mapping and theoretical analyses.

Fault traces are observed to be discontinuous features consisting of numerous discrete segments. Fault segment geometry may be quite complex, however relatively simple echelon arrays are common. Discontinuities on individual faults are found at many length scales and are observed in different tectonic settings and rock types. Furthermore, discontinuities control the distribution of slip along faults following earthquakes, and in some cases, the distribution of seismicity along the fault systems. To study discontinuities, such as echelon offsets, we derive a two-dimensional solution for any number of nonintersecting cracks arbitrarily located in a homogeneous elastic material. The solution includes the elastic interaction between cracks. Crack surfaces are assumed to stick or slip according to a linear friction law. For faults comprising many segments, the ratio of slip to total fault length significantly underestimates the stress change on the fault, whereas the ratio of slip to segment length slightly overestimates the stress change. Two parallel echelon cracks are analyzed to determine: (1) the tractions acting on fault surfaces and the potential for frictional sliding, and (2) the stress state near closely spaced faults and the potential for secondary fracturing and deformation. Parallel echelon cracks subjected to a uniform remote shear stress exhibit opposite behavior for right- and left-stepping discontinuities. For right-lateral shear and left-stepping cracks with overlapping ends, normal tractions acting across the overlapped crack ends increase and inhibit frictional sliding, whereas for right-stepping cracks, normal tractions decrease on the overlapped ends and facilitate sliding. The mean compressive stress between right-stepping cracks also decreases and promotes the formation of secondary fractures which tend to link the cracks and allow slip to be transferred through the discontinuity. For left-stepping cracks, secondary fracturing is more restricted spatially and tends not to link the cracks until greater shear is applied. Opposite behavior results if the sense of shear is left-lateral. For vertical strike-slip faults the mean stress is shown to be approximately proportional to the free-surface vertical displacements. Predicted distributions of surface displacements and deformation are compared with observations near a left-step in the Coyote Creek fault and a right-step in the Imperial-Brawley fault system; both in southern California. Seismicity is related to discontinuities in fault geometry in some regions. Our results suggest that for right-lateral shear, right-steps are sites of enhanced seismicity, whereas left-steps store elastic strain energy and are potential sites of large earthquakes. Imperial Valley seismicity, as well as aftershocks of the 1966 Parkfield, California earthquake, cluster near right-steps in faults. Discontinuities in geometry may play an important role in rupture triggering and stopping, and as a source of the fault heterogeneity required by source-mechanism studies.

Reports

Johnson, A. M., and Aydin, A., Faulting of porous sandstone: U. S. Geol. Surv. Bull., approved by Dir. March, 1979, 30 p.

Segall, P., and Pollard, D. D., 1979, Discontinuous geometry and fault mechanics: (abs.) Abstracts with Programs, Geol. Soc. Am. An. Mtg., v. 11, # 7, p. 513.

McGarr, A., D. D. Pollard, N. C. Gay and W. D. Ortlepp, 1979, Observations and analysis of structures in exhumed mine induced faults: U. S. Geol. Sur. Open File Report #79-1239, p. 101-120.

Coherent Seismic Wave Analysis

9930-02296

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Investigations

Our goal is to collect and interpret high quality seismic data for a variety of geophysical experiments. Among these are the search for seismic velocity structure in specific areas of the crust, teleseismic delay studies related to large scale crustal features and geothermal systems, and temporal velocity variation studies using controlled sources.

Results

In our last report, we described the results to date of a teleseismic P-wave delay inversion for heterogeneous velocity structure at the Coso geothermal area, California. The final interpretation of that study is in press, due to come out early 1980. Teleseismic P-wave arrivals were recorded by a dense array of seismograph stations located in the geothermal area. The resulting pattern of relative residuals reveals an area showing approximately 0.2 seconds excess traveltime that migrates with changing source azimuth, suggesting that the area is the "delay shadow" produced by a deep, low-velocity body. Inversion of the relative residual data for three-dimensional velocity structure determines the lateral variations in velocity to a depth of 22.5 km beneath the array. An intense low-velocity body, which coincides with the surface expressions of late pleistocene rhyolitic volcanism, high heat flow and hydrothermal activity, is resolved between 5 and 20 km depth. It has maximum velocity contrast of over 8% between 10 and 17.5 km. The shallowest part of this body is centered below the region of highest heat flow; at depth it is elongate in approximately the N-S direction. The hypothesis that this low-velocity body is caused by the presence of partial melt in the middle crust is consistent with the local seismic, geologic, and thermal data.

Since then we have turned to the problem of seismic data collection and data management. For many experiments relevant to crustal structure in California, the USGS central California permanent seismic network is ideally suited and can provide high quality array data over a vast area. Until recently, however, access to the network's data was difficult and awkward, practically limited to relatively small amounts of strip-chart playout. The tremendous potential of the network was sadly limited by the available means to access and manage its output. To address this problem, an effort was begun (by W. Ellsworth) to bring the California network data into more accessible form using our Eclipse computer systems. We have been participating, full time, in this effort by developing specific elements of software. This is a large job without much glory, and it is far from finished. However, the result should open the way for some exciting new work in which high speed array processing techniques can be applied to central California seismic data.

Reports

Reasenberg, P., Ellsworth, W., and Walter, A., 1980, Teleseismic evidence for a low-velocity body under the Coso geothermal area: Journal of Geophysical Research, v. 85, in press.

INTERPRETATION OF DEEP CRUSTAL REFLECTION DATA FOR STRUCTURE AND PHYSICAL PROPERTIES NEAR ACTIVE FAULTS

14-08-0001-17717

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SUMMARY

Research consists of studying the COCORP Parkfield line across the San Andreas fault. Data quality is poor so that most of our effort has gone into analyzing and improving the seismic data quality. The seismic reflection section is so poor that it does not even show the Tertiary sediment-Salinian granite contact even though this should be a major reflector. Causes for poor reflections are: 1) Noisey field records, 2) incorrect stacking velocity, 3) static corrections, 4) complex raypaths that don't stack, 5) reverberations, 6) surface conditions, 7) complex geology. Noisey field records seem to be a characteristic of the recording instruments as determined by comparison with data of T. McEvilly from a similar reflection study of the San Andreas fault. The effect of noisey field records may be minimized by editing of the uncorrelated field records, and the seismic contractor may agree to do this.

Changing the velocity function has resulted in better shallow reflections over the Salinian block. New static corrections are now being calculated; this is a lengthy process. Variable-range stacks seem to improve data quality in the vicinity of the San Andreas fault. Here possible diffractions can be seen to over 4 sec. record time. Constant velocity sections

enhance numerous dipping events not all of which are associated with the fault. A seismic model indicates that the reflection pattern can be complex. In spite of interference from noise, numerous events can be recognized in the field records, more in fact than appear on the final seismic section. This suggests that the geology around the San Andreas fault could in fact, be resolved by reflection profiling. A combination of poor field records and difficult processing parameters is degrading the data rather than impossible geology.

Crustal Inhomogeneity in Seismically Active Areas

9930-02231

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Investigations

1. A practical method to compute the frequency-amplitude response characteristic of our short-period seismic telemetry system was devised, in collaboration with Mary O'Neill Allen. The method allows for the different amplifiers, discriminators, and recording media that have been used.

2. Design and implementation studies are continuing, in cooperation with Peter Ward, that will result in an online, realtime earthquake data acquisition system for the central California telemetered seismic network. Current emphasis is related to choosing the right hardware for the rather large delay line required. For a system that can handle 512 seismic signals, each digitized at a rate of 100 Hz, a 50-second delay line requires a capacity of 2½ million words of memory.

3. The in-house PDP 11/34 and 11/70 computers are being evaluated with respect to memory capabilities in computating hypocenters and magnitude in an online, realtime environment.

Results

1. An open-file report (by Stewart and O'Neill) that describes the frequency-amplitude response characteristics of our short-period seismic telemetry system is being prepared. We construct individual response curves for the four main components of the telemetry system, and then represent each curve by an appropriate number of poles in the complex plane. Total system magnification is then found by complex multiplication, in the frequency domain, of the analytical representation by poles for each of the four system components. These four components are: (1) seismometer and L-pad; (2) seismic amplifier and VCO; (3) discriminator; and (4) recording media. Included in the recording media are the Develocorder and film viewer, Siemens oscillograph, and various analog-to-digital converters. We found that from 1 Hz up to about 8-10 Hz the shapes of the response curves are fairly uniform. At higher frequencies the shape depends greatly on which of several types of discriminators were used, and which recording medium was selected. Peak magnification as seen on the Develocorder viewer screen, with the field attenuator set at 12 dB, is 1.2×10^6.

2. In cooperation with Peter Ward, concepts and plans are being developed to implement an online earthquake data acquisition system. The system is being designed to handle 512 short-period seismic telemetry channels, each channel being digitized at a rate of 100 Hz. Rex Allen's microprocessor-based online earthquake detection system is expected to provide the trigger to this data acquisition system. We have investigated the feasibility of contracting out for the system design and construction, and more recently have looked closely at augmenting our in-house PDP 11/34 to do the job. The key element of either approach is how to implement a delay line of 50-100 seconds length, in order to save adequate prehistory of the start of the seismic event, and to allow adequate time for the online detection system to decide that a real seismic event is in progress. Not too surprisingly, the high cost of bulk semiconductor memory has led us to consider using a moving-head disk as the delay-line element.

3. As the online earthquake detection and location system based on the now-obsolete CDC-1700 is being ended soon, I have begun to look into the in-house PDP 11/34 and 11/70 system as the replacement for this computer to do the online location and magnitude calculation. (Rex Allen's microprocessor-based system will do the online detection of events and p-phase timing, and will pass the relevant information on to the PDP 11/34 or 11/70.) HYPO71 was converted to the PDP 11/70, but had to be greatly stripped down in order to fit. It is entirely memory-resident, but uses nearly all of available memory. It is much too large to run on the smaller PDP 11/34, as is. Either a much more compact hypocenter location program will have to be found, or an overlay system will have to be used, for either the PDP 11/34 or 11/70.

Reports

Lee, W. H. K., and Stewart, S. W., 1979, Microearthquake networks and earthquake prediction: Earthquake Information Bulletin, in press.

Fault Zone Structure and Seismicity in Central California

9930-02392

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See Earthquake Data Processing report

9900-90034

PETROLOGIC COMPARISON OF CATACLASTIC ROCKS FROM SHALLOW AND DEEPER CRUSTAL LEVELS WITHIN THE SAN ANDREAS FAULT SYSTEM OF SOUTHERN CALIFORNIA

14-08-0001-17732

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In a continuing evaluation of cataclastic rocks within the San Andreas Fault System of Southern California, the San Gabriel Fault (Fig.1), a deeply eroded late Oligocene to mid Pliocene precursor to the San Andreas, was chosen for petrologic study as it should provide intrafault material representative of deeper crustal levels. Cataclastic rocks along the present trace of the San Andreas in this area are exclusively a variety of fault gouge which is essentially a rock flour with a quartz, feldspar, biotite, chlorite, amphibole epidote, and Fe-Ti oxide mineralogy representing the milled-down equivalent of the original rock (Anderson et. al, in press). Fault gouge along with breccia is likewise common along the San Gabriel Fault but only where the cataclasized zone is several tens of meters wide. At several localities, the cataclasized zone is extremely narrow (few centimeters) and the cataclastic rock type is cataclasite (Higgins, 1971), a dark, aphanitic, and highly comminuted and indurated rock. Conceivably, such narrowing of the cataclasized zone and intensity of cataclasis is what might be expected in the higher confining pressure of deeper crustal levels.

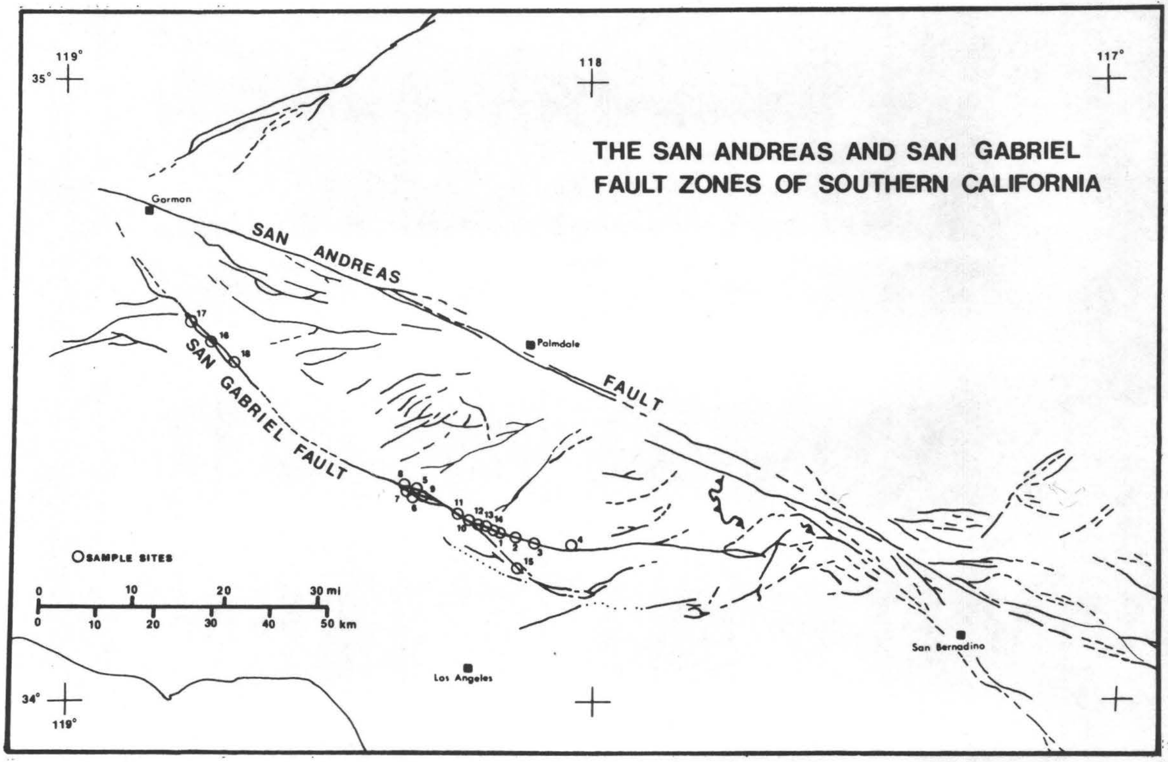

Figure 1. The San Andreas and San Gabriel Fault Zones of Southern California and sites chosen for petrologic study

The cataclasite and gouge along the San Gabriel Fault is considerably finer grained than gouge along the San Andreas. The average grain diameter for the San Andreas gouge is 0.01 to 0.06 mm whereas for the San Gabriel cataclastic rocks it ranges from 0.0001 to 0.007 mm. Moreover, while the San Andreas gouge remains particulate to the smallest grain size, the ultra-fine grain matrix of the San Gabriel cataclasite is recrystallized.

As we have already observed for the San Andreas, the San Gabriel cataclastic rocks exhibit minimal evidence of chemical mobility and mineral reequilibration. There appears to be some mobility of Li, Rb, and Sr and a few biotites show compositional changes that are directly related to cataclasis. This does not include alteration features (e.g. chloritization, sericitization, and hematization) that are common but not directly tied to the deformation. For most sites, the composition of minerals (e.g., plagioclase, alkali feldspar, biotite, amphibole, chlorite and the Fe-Ti oxides) can be directly related to mineral compositions in rock types on one or both sides of the fault and in general have not reequilibrated with the imposed P-T regime during cataclasis. For some sites, mineral and whole rock chemical data show that mixing within the cataclasized zone is not uniform but rather that lithologies on side of the fault may have a disproportionally larger contribution to the make-up of the intrafault material.

REFERENCES

Anderson, J. L., R. H. Osborne, and D. F. Palmer (in press), Petrogenesis of cataclastic rocks within the San Andreas Fault Zone of southern California, U.S.A.: Tectonophysics.

Higgins, M. W. (1971) Cataclastic rocks, In: U.S.G.S. Professional Paper 687, 97.

A Study of Mylonitic Rocks from Major Fault Zones

14-08-001-17757

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Investigations

1. Initial field work was conducted in five areas of southern California. Samples of fault rocks and also uncataclasized rocks, adjacent and within fault zones, were collected. The five areas studied to date are:

a. A two mile wide traverse across Upper Lytle Creek Ridge from Lone Pine Canyon (San Andreas rift zone) to the canyon bottom of the North Fork of Lytle Creek in the Telegraph Peak quadrangle. Exposed along this traverse is a 2000 ft. wide cataclastic zone of the Punchbowl fault zone, plus a number of smaller cataclastic zones. The Punchbowl fault zone here consists of slices of several different rock types which are bounded by major shear surfaces. The slices have been "shuffled" together during a complex history of faulting. Cataclastic rock types range from mylonitic schists, through various sorts of breccias, to noncoherent gouge. Also present are scattered lenses of virtually pure actinolite which represent serpentinite altered by metasomatism.

b. Samples were collected along a 3500 ft. section across strike of a mylonite zone in the Crafton Hills northwest of the town of Yucaipa. Typical rock types here are blastomylonite and mylonite.

c. Several small shear zones on Blue Ridge (Mescal Creek quadrangle) were investigated. These zones are close to the portion of the Punchbowl fault zone that passes through this area. Mylonitized Pelona schist is the major rock type. However, one zone has a 50 ft. wide, fault-bounded slice of serpentinite with monomineralic, lens-shaped masses of actinolite.

d. Two thin thrust zones in the eastern Sierra Pelona were sampled. Fault rocks here are gouge and incoherent breccias.

e. The classic area in Cucamonga Canyon was sampled to provide comparison of the other zones with a relatively deep-seated cataclastic zone.

2. Thin sections have been prepared from samples collected. The thin sections were petrographically examined to determine the minerals present, what reactions may have occurred, and whether the reactions may have accompanied shearing.

3. Selected samples have been analyzed with the electron microprobe. The microchemical data is used to investigate mineral reactions and to determine the physical conditions of formation of fault rocks.

Results

1. Extensive retrograde metamorphism of the rocks has occurred in the fault zones of the first three areas listed above. The reactions involve hydration or hydration and carbonation. Large volumes of rock have been affected.

2. No evidence of prograde dehydration or decarbonation reactions that accompanied faulting has been found. Given the assemblages present in many of the rocks, observable dehydrations should be in evidence if any significant transitory heating due to friction had occurred; hence such transitory heating seems to be ruled out in the Upper Lytle Creek Ridge - Blue Ridge and Crafton Hills areas.

3. Compositions of Ca-amphiboles (actinolite-hornblende series) from mylonitic schists from Upper Lytle Creek Ridge and Blue Ridge indicate that the geothermal gradient was intermediate over a range of grades from epidote-amphibolite facies through lower greenschist facies. The amphibole compositions are similar to those in rocks from intermediate P/T (or even somewhat higher P/T) regional metamorphic terrains. The presence of such amphiboles tends to rule out significant frictional heating in the Punchbowl fault zone or in the immediately adjacent portion of the San Andreas fault zone.

4. The three conclusions listed above suggest that the fluid pressure was relatively close to the load pressure in the zones of the Upper Lytle Creek Ridge, Blue Ridge, and Crafton Hills areas. However, it is premature to extend this as a generalization to other parts of the San Andreas system. The relative importance of frictional heating may vary with relative differences in the fluid pressure. More fault zones need to be studied to determine if frictional heating was important in any part of the San Andreas system or whether relatively high fluid pressures are characteristic in the fault zones at depth.

Stress Corrosion Cracking in Premonitory Earthquake Events

1408-001-16798

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Investigations

Stress corrosion crack growth is a well-developed field of material sciences possessing a large body of theoretical and experimental literature pertaining to the behavior of glass and ceramics. However, its effect on geologic materials involved in geologic processes is considerably less well understood. The purpose of this study was to examine the potential role of stress corrosion crack growth in geologic materials with respect to the earthquake process both in terms of a physical model and with regard to available data on fault mechanics which would constrain or identify aspects of such a model.

Results

1. It is possible to model aseismic fault creep as a form of stress corrosion crack growth in asperities along the fault plane. Order-of-magnitude calculations indicate that for an aseismic creep rate of 5 cm/yr, crack growth velocities should be on the order of 10^{-6} m/sec. Such a velocity is in the mid range of region I of crack growth curves for quartz. Thus, the presence of stress corrosion in the fault plane introduces chemical processes into a problem heretofore considered to be totally mechanical.

2. The depths at which faults are locked have been inferred from surface measurements of accumulated strain in the vicinity of the fault trace. Such inferences, unconstrained by realistic considerations of rock mechanics in a fault plane environment, have led to unrealistic estimates of this locking depth. The inclusion of the phenomenon of stress corrosion crack growth through a model as proposed above will better constrain the fault mechanics problem and will provide a more physical model of fault movement. This consideration allows fault depths to be less than previously estimated.

3. Seismological literature dealing with the seismic activity sequence can serve as a data source for estimating the time dependence of the stress distribution along a fault. Thus, constraints on the stress relaxation due to stress corrosion crack growth may be inferred from the foreshock-mainshock-aftershock sequence. This would make it possible to associate aseismic creep with seismic activity. In this view, the sequence of aftershock activity would be influenced by changes in the humidity at the crack tips--such changes created by the moisture redistribution arising from the mainshock. If this is correct, the sole use of stress analyses of tectonic movements for correlating mainshocks with aftershocks will be misleading.

SOME SPECIFIC EXPERIMENTAL AND FIELD STUDIES PERTAINING DIRECTLY TO THE MECHANISMS OF SEISMIC AND ASEISMIC FAULTING

Contract No: 14-08-0001-17662

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Investigations

1. Acoustic emission studies(event counting,ring-down counting,amplitude distribution and pulse width) of slow(subcritical) and fast tensile cracking of rocks in wet environments using the double torsion testing geometry.Study of stress-dependent morphological features on quartz and glass fracture surfaces.Determination of Fracture surface energies for some rock-forming minerals using an indentation technique. Compilation of experimentally determined Fracture Mechanics parameters for geological materials.

2.Experimental study of aseismic fault slip in nominally pure,wet quartz rocks at 300°C and an effective confining pressure of 1.5kbar.

3.Field studies,optical and electron microscopy,microchemical analyses and theoretical studies of the factors affecting the genesis of fault rocks with particular attention being focussed on the Alpine Fault Zone, New Zealand.

Results

1.1 The critical stress intensity factor(K_{Ic}) for catastrophic tensile failure in Westerly Granite was found to be approximately 1.74 $MN.m^{-3/2}$ and this value varied only slightly with orientation. This granite shows significant acoustic emission(frequency range 100-300 kHz) even at stress intensity factors down to 0.6 K_{Ic},which corresponds to crack velocities of ca. 10^{-8} $m.s^{-1}$.

1.2 The crack velocity(v) in Westerly Granite is related to the stress intensity factor(K_I) by $v \propto K_I{}^n$ for both liquid water and moist air environments.Over the range of crack velocities studied(ca.10^{-8} to 10^{-4} $m.s^{-1}$) v increases monotonically with increase in K_I.

1.3 As was previously found for a gabbro,acoustic emission count rates and ring-down count rates as a function of K_I are of the same form as the v/K_I results.Acoustic emission rates can thus be correlated with crack velocities.The slopes of log event-rate/log K_I diagrams(n_E) and log ring-down count rate/log K_I diagrams(n_R) are presented with values of n below. Figures in brackets are the correlation coefficients.

	Air(30% R.H.)	Water
n	39.1(0.968)	34.8(0.987)
n_E	39.6(0.991)	31.1(0.938)
n_R	38.8(0.972)	35.8(0.969)

1.4 The exponent b in the amplitude distribution power law i.e. $n(a) = (a/a_o)^{-b}$ decreases with increasing K_I for both wet and "dry" experiments.Here n(a) is the fraction of the emission population whose peak amplitude exceeds amplitude a,and a_o is the lowest detectable amplitude.The b values for the wet tests at low K_I are higher and show a more marked dependence on K_I than those corresponding to "dry" conditions. At high fractions of K_{Ic} the b-values for wet conditions fall to similar values to those observed in "dry" tests.These results are consistent with the pattern observed in previous studies on a gabbro.

1.5 We conclude that the characteristics of acoustic emission from rock can be used to monitor the state of stress in the vicinity of crack tips and the crack velocity as well as the "humidity" of the crack tip environment. These results may be directly applicable to the study of earthquake precursors based on seismology.

1.6 Stress-dependent morphological features have been found on quartz and glass tensile fracture surfaces.The nature of this stress dependence has been determined by experiment.For glass the size of the characteristic feature is related to crack branching.In quartz the characteristic feature depends upon crystallographic orientation and while its size depends on the crack-system energy it is not directly related to crack branching. Experimental results follow an equation of the form $A^* = \sigma_f r^{*\frac{1}{2}}$,where σ_f is the fracture stress,r^* is the size of the characteristic feature and A^* is a constant.Experimentally determined values for A^* for quartz are as follows:

Synthetic quartz(normal to c axis)	$A^* = 2$ $MN.m^{-3/2}$
Synthetic quartz(parallel to m plane)	$A^* = 3.9$ $MN.m^{-3/2}$
Natural Brazilian quartz(normal to c axis)	$A^* = 3.7$ $MN.m^{-3/2}$

The natural Brazilian quartz has a K_{Ic} value of 2.4 $MN.m^{-3/2}$(determined by bend tests) in contrast to the lower values of 0.8-1.0 $MN.m^{-3/2}$ found for synthetic quartz.As both types of quartz have rather similar structurally bound water contents(ca.200H/10^6Si) we conclude that the former has significantly greater resistance to fracture than the latter due to some as yet undetermined ultra-microstructural phenomenon.

1.7 Based upom an analysis of indentations around a sharp Vickers indenter we have determined fracture surface energy(Γ) values by experiment for the following materials:quartz,calcite,pyrite,spinel, galena and microcline.Experiments were run at room temperature initially, but some were also run on quartz and calcite at temperatures up to 200°C.

1.8 An exhaustive literature survey has allowed the compilation of the following experimentally determined Fracture Mechanics parameters: (a) K_{Ic},G_c and Γ for rocks and minerals,(b) calculated values of the thermodynamic surface energy (c) subcritical crack propagation parameters-stress dpendence of crack velocity and activation enthalpy for crack propagation.

2.1 A long term(4 month) stress relaxation experiment on wet pre-faulted Oughtibridge Gannister(a pure orthoquartzite) at 300°C and an effective confining pressure of 1.5 kbar confirmed our earlier experiments in which we observed no apparent influence of pore water on the stress required for sliding. This result contrasts with the dramatic weakening effect of water on Tennessee Sandstone(a quartz sandstone with up to 15% of the total made up of interstitial phyllosilicate phases)at strain rates below ca. 10^{-6} s^{-1} which we attributed to a combination of stress corrosion and pressure solution controlled processes at asperities.The latter mechanism is perhaps facilitated by the presence of phyllosilicate phases.

2.2 Long term stress relaxation experiments on pre-faulted specimens of Mojave Quartzite(a pure quartz rock from the Hodge Volcanic series,Mojave Desert-containing trace quantities of mica) at 300°C and an effective confining pressure of 1.5 kbar showed that this material when wet undergoes a similar dramatic weakening to that shown by Tennessee Sandstone on lowering the strain rate below ca.10^{-6} s^{-1}.The strength of the dry material is affected only very slightly by reducing the strain rate in the range from 10^{-4} s^{-1} to 10^{-9} s-1.

3.1 The background picture of the Alpine Fault zone,which we have developed from 2 seasons field work,has formed the framework for the interpretation of our more detailed microstructural studies in this contract period. An important finding of our background work is the recognition on structural grounds(supported by new K-Ar age data) that the various fault rock fabrics and their distribution within the fault zone all developed during the Late Cainozoic phase of dextral-reverse-oblique shear.This forms the justification for our basic working hypothesis that in passing from the downthrown to the upthrown side of the fault zone we are seeing fault rock fabrics derived from progressively greater depths.

3.2 A reinterpretation has been proposed of the distribution of Cretaceous lamprophyre dyke swarms in the vicinity of the Alpine Fault which allows all strike-slip displacement to have occurred in the Cainozoic,in accord with the sea-floor spreading data from the surrounding oceans.

3.3 Based upon sub-grain size and dislocation density measurements the stress for the onset of mylonitization in the schists of the Alpine Fault zone has been estimated to lie between 400-800 bars.In a similar way the stress required for cataclasis of the granite in the fault zone was estimated to be ca. 2.5 kbars.Data pertain to the Saddle Creek section.

3.4 Studies of pseudo tachylyte from the Thompson River section show that although some are still glass,devitrification had occurred to a fine-grained homogeneous rock consisting of quartz,plagioclase,muscovite,chlorite.

3.5 Studies of the mixed brittle/quasi plastic behaviour in the Outer Hebrides Thrust zone have shown that intermittent seismic slip on discontinuities within an otherwise ductilely deforming shear zone can occur. If displacement in such zones is estimated by integrating shear strain across them it may be severely underestimated.In dry mylonite belts the products of seismic slip may well be recognised as pseudotachylyte,but in more common hydrated mylonite belts such direct evidence will probably be lacking.

3.6 A preliminary attempt has been made to link the distribution of fault rock types in sialic crust with metamorphic environment and the dominant quartz deformation mechanism for a strike-slip fault deforming steadily by aseismic shear.The distribution of rocks deforming by cataclasis,crystal plastic flow,pressure solution and Coble creep have been sketched out. During seismic faulting,cataclasis is likely to be the main deformation mechanism at all crustal levels because of the high slip rates and power dissipation.Under dry conditions friction melting with the production of pseudotachylyte may occur at depths in excess of 1km,provided that slip is localised within a thin zone,but these latter textures may be obliterated by later aseismic shearing.

3.7 From the geological evidence on the levels of stress and power dissipation during slip in fault zones we conclude that both high stress($\geq$1 kbar) and low stress($\leq$ 100 bars) faulting occurs,depending upon local conditions of pore fluid pressure.Higher stresses are more usually associated with immature fault systems,especially reverse faults developed in crystalline basement.

3.8 We propose that the Alpine Fault zone(driven by high shear stresses) is an ideal target for a drilling programme designed to provide a control on similar work on the San Andreas Fault(driven by low shear stresses). These holes could be used for in-situ stress determinations,heat flow measurements and to provide material for analysis of deformation textures.

Reports

Atkinson,B.K.(1980) Discussion on acoustic emission and fracture of rocks under different chemical environments.*In* Proc.Int.Symp. on Earthquake Prediction,UNESCO,Paris,1979(in press).

Atkinson,B.K.(1980) A compilation of experimentally determined Fracture Mechanics parameters for geological materials(in preparation).

Atkinson,B.K. and Avdis,V.(1980) Fracture surface energy of some rock-forming minerals determined using an indentation technique(in prep.)

Norton,M.G. and Atkinson,B.K.(1980) Stress-dependent morphological features on quartz and glass fracture surfaces(prepared for Geology).

Rutter,E.H.(1980) A note on the mechanical properties of kaolinite "fault gouge" at moderate confining pressure,20^{o}C.Int.J.Rock Mech. Min.Sci. and Geomech.Abstr.(in press).

Sibson,R.H.(1979) Fault rocks and structures as indicators of shallow earthquake source processes.Proc.Conf.VIII,"Analysis of actual fault zones in bedrock".NEHRP April 2-5,1979(USGS,Menlo Park,Ca.),276-304.

Sibson,R.H.(1980) Transient discontinuities in ductile shear zones. J.Struct.Geol.(submitted).

Sibson,R.H.(1980) Power dissipation on faults during seismic slip:geological evidence.Proc.Conf.IX,"Magnitude of deviatoric stresses in the earth's crust and upper mantle".NEHRP,July 29-Aug 1,1979 (USGS,Menlo Park,Ca.).

Sibson,R.H.(1980) Lamprophyre dike swarms and the timing of movement on the Alpine Fault.N.Z.J.Geol.Geophys.(submitted).

White,S.H.,Burrows,S.E.,Carreras,J,Shaw,N.D. and Humphreys,J.(1980) Mylonite development in ductile shear zones.J.Struct.Geol.(submitted).

ROCK MECHANICS

9960-01179

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Experimental Fault Creep

A cylindrical Westerly granite specimen containing a simulated fault filled with crushed Westerly granite was deformed under 300 MPa confining pressure until stick-slip occurred. The specimen was loaded at alternating apparent axial strain rates of 10^{-4} and 10^{-6}/sec over 1 mm intervals. The resulting stress-strain curve had a stepped form, with segments where loading occurred at 10^{-4}/sec becoming progressively stronger than alternate segments where loading occurred at 10^{-6}/sec. Strain-rate dependent strain hardening increased to a maximum of approximately 2.5% at 900 MPa differential stress. Above 900 MPa differential stress, the strength remained a constant 2.5% greater at 10^{-4} than at 10^{-6}/sec regardless of increased differential stress. Whereas strain rate effects on experimental fault creep are commonly masked by sample variability, this new experiment utilizing alternate loading rates clearly shows increased fault strength with increased loading rates. The stable sliding of experimental faults containing gouge under constant differential stress conditions may be governed by the strain-rate dependent strain hardening mechanism described above. If so, predictions of creep behavior may be calculated on the basis of constant strain rate experiments conducted at several alternating strain rates. The results of our creep experiments on faults containing gouge at 300 MPa confining pressure are consistent with the limited data from the one experiment conducted at 10^{-4} and 10^{-6}/sec strain rates.

Compressibility of Porous Rocks

Samples of basalt with porosities ranging from 0.3% to 25% have been studied to determine how hydrostatic loading affects porosity. Most samples show a rapid loss of pore volume to about 500 bars confining pressure, followed by a more gradual, linear decrease in porosity at higher confining pressures. This indicates rapid initial closing of interconnecting cracks, followed by closing of the more stable, low aspect ratio vesicules.

These results along with V_p and V_s measurements currently being performed, will be of use in providing parameters for studying earthquake mechanisms as well as in understanding geothermal systems.

Pore Volume Changes in Gouge During Shearing

Experiments are being performed to extend previous investigations of pore volume changes during shearing of crushed granite into the realm of creep.

In previous experiments performed at constant axial displacement rate, it was found that the layer of crushed granite compacted when axial load was applied, and when stable sliding started, the layer dilated and continued to dilate to the limits of displacement available, about 1 cm. No change in this behavior was observed immediately prior to stick-slip. Because stick-slip developed very rapidly in these experiments, it was thought that perhaps precursory phenomena occurred but were not observed. Therefore, we're performing experiments at constant stress to observe volume changes occurring during tertiary creep leading to stick-slip failure. Experiments performed sofar ran as follows: Samples were deformed at constant strain rate well beyond the point at which dilatancy developed. The stress was then fixed at a constant value. The sample crept at a steadily slower rate. After two days, constant strain rate loading was resumed and the stress rose to a value significantly higher than would be predicted from constant strain-rate experiments. The stress was again fixed at this new, higher level, Creep proceeded into an acceleration phase that eventually led to failure. During these creep phases, the volume increase essentially followed the creep rate periods, the volume increase rate steadily decreased and during accelerating creep, the rate at which volume increased also accelerated. When pore volume is plotted against sample displacement, however, the result is quite different. As the first creep period slowed down, the amount of volume increase for each unit of sample displacement increased. During the tertiary creep phase before failure, the volume increase versus displacement decreased. Thus, the rate at which volume increases with displacement seems to be inversely proportionate to creep rate. Experiments are now being performed to examine the strengthening effect of the first creep phase, and to investigate the relationship between strain rate and volume production rate.

Fracture and Frictional Strength of Wet Rock at Elevated Temperature

The fracture and frictional strength of franciscan greywacke is being measured at a confining pressure of 200 to 1000 bars, pore pressure of 30 bars, temperature of 150°C and 240°C and at strain rates of 10^{-4}/sec and 10^{-6}/sec. The data from these experiments will be used to get a better understanding of the cause of the induced seismicity of the geysers geothermal reservoir.

TRANSIENT CREEP AND SEMIBRITTLE BEHAVIOR OF CRYSTALLINE ROCKS

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Summary

In anticipation of beginning experimental work on transient creep of granitic rocks at moderate to high temperatures, most of the time spent on this project has been devoted to a survey of the extensive literature on the topic. Especially time-consuming recently has been a review of the enormous literature on low-temperature creep of granite. This review follows on treatments of creep of rocks in general, given by Carter and Kirby (1978) and Handin and Carter (1979), reviews that focused mainly on high temperature creep. The main results of the present survey are outlined below with a more detailed discussion given in the semi-annual report.

Low-temperature creep of granitic rocks generally appears to follow a logarithmic flow law although the time dependence is not yet firmly established (Kranz and Scholz, 1977). The creep strain is accomplished by microfracturing and the rate-controlling process for the microfracturing is believed to be chemical corrosion of stressed crack tips leading to time-dependent fracturing. Associated with the microfracturing are acoustic emissions and changes in permeability, electrical resistivity, magnetic moment, gas emission, longitudinal, radial and volumetric strains, and acoustic velocities and anisotropies (Byerlee, 1978). The stress-induced cracks are dominantly extensile in nature, resulting from elastic mismatch and stress concentrations at boundaries at high angles to the maximum principal compressive stress σ_1,(Tapponnier and Brace, 1976; Kranz, 1979a,b). These cracks appear to develop preferentially in weakened zones inclined to σ_1, and may link up in various ways with each other with other minerals and with crushed grain boundaries to produce a throughgoing fault (Kranz, 1979b). Apparently, a critical crack density, associated with a critical volumetric strain, are required for the onset of accelerating creep and eventual fracture instability (Cruden, 1974; Kranz and Scholz, 1977). Kranz (1979a) pointed out a fundamental difference in crack development in constant stress and constant strain rate tests, the former type, he believes, to be most applicable to natural deformations. The difference is that at constant strain rate, crack growth and development are limited by the rate at which stress is applied; whereas, in creep tests, crack growth is limited by the rate at which corrosive agents can decrease crack-tip strength.

The addition of temperature alters the nature of the deformation and of the flow law in many important ways. The most obvious effect is the introduction of thermal cracks resulting from differential thermal expansion of adjacent minerals, the volume of new cracks increasing exponentially with temperature (Simmons and Cooper, 1977). However, rock strengthening can result if corrosive agents are driven off by the increase in temperature (Wu and Thomsen, 1975). In the presence of H_2O at elevated temperature, permeability may decrease by dissolution of minerals in localized areas of high pore pressure and precipation of these in over-saturated regions of low pore pressure (Summers et al, 1978). There must also exist physical conditions at which corrosive and embrittling effects of H_2O give way to ductile effects by facilitating the motion of slip dislocations and diffusion (Carter and Kirby, 1978).

A most important effect of elevated temperature is the thermal activation of dislocation and diffusion processes. It is observed for ductile materials, and some crystalline rocks under confining pressure, that the activation energy for high-temperature transient creep is the same as that for steady state creep which implies that the same process controls the creep rate for both. Inasmuch as this activation energy is about the same as that for self-diffusion of the least mobile atomic species, where documented, this correspondence suggests that vacancy diffusion controls the creep rate. The deformational processes responsible for high temperature transient creep of granitic rocks are believed to be semibrittle, wherein thermally activated dislocations interact to nucleate cracks, or to aid or retard their propagation. The validity of this supposition has not been demonstrated to date and will require thermomechanical studies because of the very low strains involved. However, in one study (Tullis and Yund, 1977) in which granite was compressed to very large strains, apparently to the steady state, the behavior was demonstrably semibrittle at elevated temperature over most of the conditions employed. Thus, what appears to be needed now are experiments of granitic rocks, under modest pressure, in the elevated temperature transient creep regime with attendant careful determination of the flow processes.

References

Byerlee, J. (1978), A review of rock mechanics studies in the United States pertinent to earthquake prediction, Pure, Appl. Geophys., 116, 586-602.

Carter, N. L. and Kirby, S. H. (1978), Transient creep and semibrittle behavior of crystalline rocks, Pure, Appl. Geophys., 116, 807-839.

Cruden, D. M. (1974), The static fatigue of brittle rock under uniaxial compression, Int. J. Rock Mech. Min. Sci., 11, 67-73.

Handin, J. W. and Carter, N. L. (1979), Rheology of Rocks at High Temperatures, Proc., 4th Int. Cong. Rock Mechanics, in press.

Kranz, R. L. (1978a), Crack growth and development during creep of Barre granite, Int. Jour. Rock Mech. and Min. Sci., in press.

Kranz, R. L. (1978b), Crack-crack and crack-pore interactions in stressed granite, Int. Jour. Rock Mech. and Min. Sci., in press.

Kranz, R. L. and Scholz, C. (1977), Critical dilatant volume of rocks at the onset of tertiary creep, J. Geophys. Res. 82, 4893-4898.

Simmons, G. and Cooper, H. W. (1977), Thermal cycling cracks in three igneous rocks, J. Geophys. Res., in press.

Summers, R., Winkler, K. and Byerlee, J. (1978), Permeability changes during flow of water through Westerly granite at temperatures of 100° to 400°C, J. Geophys. Res., 83, 339-344.

Tapponnier, P. and Brace, W. F. (1976), Development of stress-induced microcracks in Westerly granite, Int. J. Rock Mech. Min. Sci., 13, 103-112.

Tullis, J. and Yund, Y. A. (1977), Experimental deformation of Westerly granite, J. Geophys. Res., 82, 5705-5718.

MECHANICS OF EARTHQUAKE FAULTING

9960-01182

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Investigations

1. A simple generalized numerical model for analysis of laboratory fault friction experiments and for analysis of interactions in natural fault systems was developed. Using this model, experimental observations of quasi-static oscillatory fault slip, accelerating stable slip prior to stick-slip instability, creep relaxation and fault creep events on the San Andreas fault were simulated.

2. Experimental and theoretical study of the mechanics of preseismic fault slip continued. Investigations during the report period emphasized the effects of strain rate in controlling the amount and duration of premonitory stable slip.

3. Rock friction experiments to establish the possible effects of small amounts of water adsorbed from the atmosphere were completed. The purpose was to verify a suspected link between water weakening by adsorbed surface water and the time- and velocity-dependent friction effects that have been shown to cause stick-slip instability and related phenomena. The friction of carefully dried samples in contact with a dry Argon atmosphere (<1 ppm H_2O) were compared with identically dried samples in contact with humid argon or exposed to the atmosphere.

4. Several investigations related to faulting and the earthquake source were begun during the report period by visiting scientists: Donald Simons (Brown University and R & D Associates) and Ze'ev Reches (Weizman Inst., Rehovot, Israel) and graduate students Andy Ruina and Paul Okuba.

Results

1. The numerical model developed during this report period uses a deterministic displacement stepping procedure to simulate the force, displacement and velocity history for fault slip. The model can accommodate complicated loading histories and incorporates a previously developed constitutive law for the fault (Dieterich, 1979). Possible two-dimensional elastic effects resulting from slip propagation are represented using scalar stiffness parameters derived from appropriate fault dislocation calculations. The simulations, in quantitative agreement with experiments show that low normal stress and high stiffness favor stable slip and high normal stress and low stiffness enhance the tendency for unstable fault slip (stick-slip). For combinations of stiffness and normal stress near the boundary separating stable sliding from stick

slip quasi-static slip oscillations resembling slow stick-slip events are sometimes observed experimentally. In the model these oscillations arise directly from interactions between the constitutive law for the fault and the stiffness and are favored by high loading rates and a large positive velocity dependent term in the constitutive law. A possible natural counterpart for this type of slip is the creep events seen on the San Andreas fault. For episodic creep events on the San Andreas fault at Bear Valley, California, simulations scaled for a depth of slip of 1.3 km and a loading rate of 2.0 cm/yr are in good agreement with the shape of the recorded displacement vs time curves, average period separating events and the peak velocity during the creep events.

2. Direct shear experiments at 250 bars normal stress and large scale biaxial experiments at similar stresses always show slowly accelerating fault creep preceeding unstable fault slip with the amount of premonitory slip increasing as loading rates are decreased. Similar results relating rate of loading to the amount of premonitory slip have been previously reported from other laboratories for stresses exceeding one kilobar. Figure 2 shows experimental results for slip on Westerly Granite. The solid curves denote quasi-static force-displacement path and dashed curve denotes unstable slip. Note especially, that instability occurs following peak stress and stabilization of stick-slip at the lowest loading rates. Figure 3 shows a simulation of the experiment using the model described above. Input parameters for the model are derived from independent measurement of consititutive parameters and machine stiffness. The good agreement with the observations is taken as further support for the constitutive model. In the model, some amount of premonitory creep is intrinsic to the interactions between the elastic element that loads the fault and the fault constitutive properties.

3. Direct shear friction experiments on conventionally prepared, air-dried samples display time- and velocity-dependent effects that have been shown to underly the mechanism for stick-slip instability. Experiments on quartzite conducted in a dry argon atmosphere (< 1 ppm H_2O) using samples that were previously carefully cleaned and dried at 300°C in dry Argon, show greatly reduced or no time- and velocity-dependence and do not have the usual large amplitude stick-slip oscillations. Brief exposure of the dried samples to the atmosphere or to humid argon restores the time- and velocity-dependent friction effects and re-establishes the stick-slip cycles. In addition the dry samples have a higher coefficient of friction than the samples exposed to a humid atmosphere. The effects seen in conventional atmospheric experiments and in these tests following exposure of the dry samples to a humid atmosphere are interpreted to be caused by adsorbed surface water that causes weakening at points of contact between the surfaces where the stresses are high. This water weakening reduces asperity strength causing the observed overall decrease in the coefficient of friction and also results in time- and velocity-dependent creep at the points of contact. Similar surface creep effects caused by adsorbed water have been reported in the literature for micro-indentation experiments.

Reports

Dieterich, J. H., 1979, Modeling of rock friction: 1. Experimental results and constitutive equations, J. Geophys. Res., 84, 2161-2168.

Dieterich, J. H., 1979, Modeling of rock friction: 2. Simulation of preseismic slip, J. Geophys. Res., 84, 2169-2175.

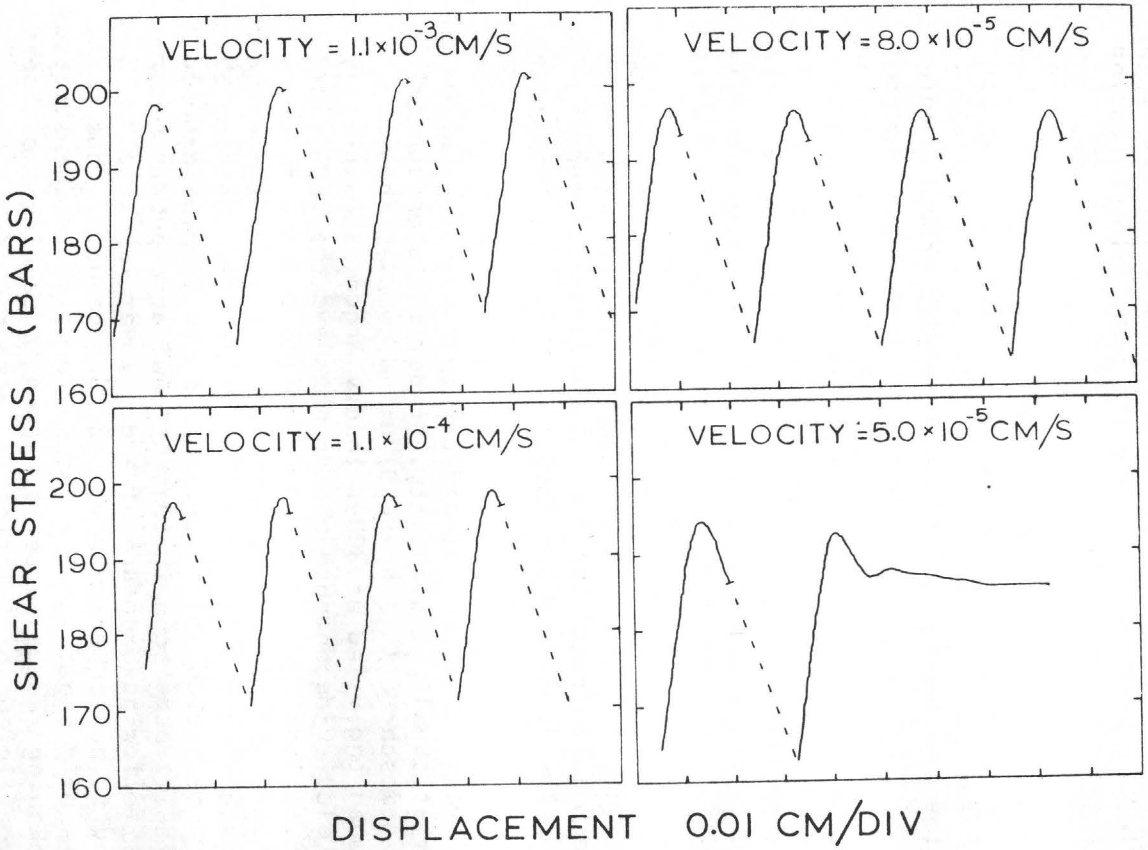

Fig. 1: Stick-slip on rough-ground surfaces of Westerly Granite at 250 bars normal stress. Dashed curves denote displacements during rapid, unstable slip.

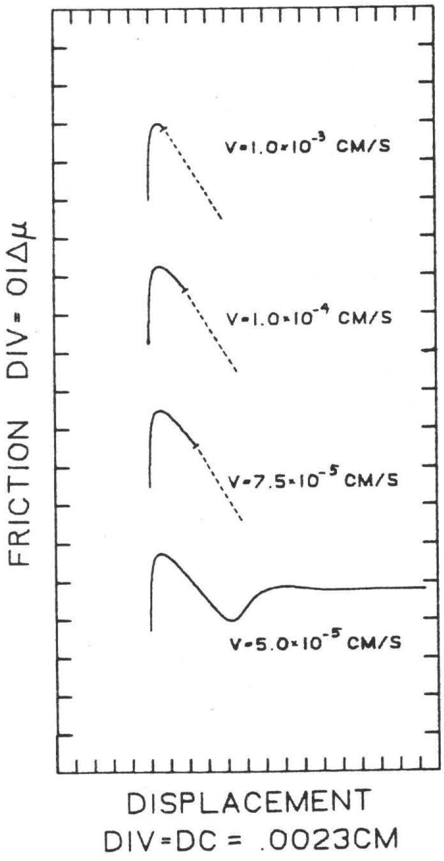

Fig. 2: Numerical simulation of the experiments of Fig. 1. Dashed curves denote unstable slip. Displacement scale is experessed in terms of the parameter DC which is used in the calculations. Vertical scale Δμ is the change in coefficient of friction μ = shear stress / normal stress.

Experimental Rock Mechanics

9960-01180

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Investigations

1. Pressure effects on the rheology of rocks.

2. Water weakening of quartz

3. Plasticity of rock-forming minerals: Spinel

Results

1. The published literature on the effects of confining pressure and state of stress on rock deformation behavior was recently reviewed and several conclusions were drawn:

   a. Three major regimes are defined: the brittle regime where failure by fracture on faulting occurs; the semi-brittle regime, in which through-going fractures or faults do not form but where both microfracturing and intracrystalline glide occur; the ductile regime, in which specimen strains are accomplished by plastic deformation mechanisms, without important micrfracturing. Each of these regimes have their own pressure effects on strength.

   b. The ratio of the least principal stress to the applied differential stress is the primary factor controlling the transitions between the above regimes.

   c. Application of the above results to the earth suggests that brittle processes may be far more important in limiting stresses in the lithosphere than previously thought, especially in regions of extension, where the least principal stress is approximately horizontal and less than the lithostatic pressure.

2. Work continues in the exploration crystallographic orientation effects on the creep of hydrolytically weakened synthetic quartz crystals. We have also developed a cold swaging technique for sealing water in silver capsules with quartz samples and are starting hydrothermal treatment experiments on quartz crystals at high pressure. We intend to establish the solubility of water in quartz so that we can relate the environmental parameters of hydrothermal pressure, temperature, and creep stress to predicted creep rates.

3. In collaboration with Patrick Veyssiere of the University of Poitiers, France, we have established the basic mechanisms of plastic deformation of Mg $A\ell_2O_4$ spinel and their critical resolved shear stresses from room temperature to nearly 1000°C (Kirby, and Veyssiere, 1979; Veyssiere, Kirby, and Robier, 1979). A major result from this study is that an anomalous strengthening with increasing temperature occurs in this material, a phenomenon not yet understood. Since this spinel is thought to be similar to the structural type corresponding to the olivine composition in the lower mantle, analogies may be drawn from our experiments and may have important implications as to whether lower mantle convection can take place.

Reports

Kirby, S. H. and Veyssiere, Patrick, 1979, Plastic deformation of MgO:1.1 ($A\ell_2O_3$) Spinel at 0.28 T_m: preliminary results: Philosophical Magazine A (in press).

Veyesiere, P., Kirby, S. H., and Rabier, J., 1979, Plastic deformation of MgO: n $A\ell_2O_3$ spinels at temperatures below 1000°C (<0.5 T_m), Proc. Third Europhysical Topical Conference: Lattice Defects in Ionic Crystals, Univ. Kent, Canterbury, U. K. (in press).

Laboratory and Field Investigations of Fault Gouge

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Investigations

The overall objective of this project is to investigate fault mechanics of gouge-host rock systems through controlled laboratory experiments and correlated field studies with the emphasis on understanding the operative physical principles that govern shallow-focus earthquakes. In this report we discuss the results of investigations into four areas: (1) the development of second order fractures in simulated gouge zones; (2) calcite fabrics in shear zones; (3) studies of ultrafine simulated gouge material; and (4) studies on gouge from U.S.G.S. wells in the San Andreas fault zone.

Results

The development of second order fractures in simulated gouge zones. To date, studies of the behavior of frictional sliding of faults with and without gouge in an attempt to identify the causitive mechanisms of stable sliding, premonitory slip, and stick-slip have not led to the recognition of any fundamental or universal mechanism responsible for any of these sliding modes. There is, nevertheless, a fracture fabric formed in the gouge, which is ubiquitous and which has been observed in all types of sliding modes, as well as along seismogenic faults (Semi-Annual Report, 30 April 1978). This fabric is the en-echelon shear and extension fractures which form as a consequence of shear displacement along primary faults. In that those fractures may serve, potentially, as a means of extrapolating the laboratory results to natural fault zones, we are orienting our studies to: (1) determine the sequence of development of these fabric elements; (2) the conditions that control their development; and (3) their significance in the displacement mode and history of the shear zone. We are concentrating on fracture development as a function of dsiplacement, strain rate and effective pressure. To achieve large-displacement (up to 3 cm) that are not normally feasiable in standard triaxial tests, we have modified a two-block shear configuration to operate in a pressure vessel. Although the stress conditions are not optimal, consistant qualitative information is obtained. To date, experiments done at room temperature, dry, a confining pressure of 40 MPa and a displacement rate of 10^{-4} cm/sec show the following sequence of development of the fracture fabric. In the elastic portion of the stress-displacement curve, no fracturing occurs. At the peak strength incipient development of the R1 and R2 shear fractures is present. The R1 fractures appear to rotate to a more boundary-parallel position by translation along R2 fractures as the shear zone moves into a strain-softening behavior beyond the peak strength. Soon after this P fractures become evident. By the onset of the residual strength of the material the R1 fractures appear to have been rotated to a Y position and most of the displacement appears to have shifted from the interface with the country rock to these fractures. It is clear from experiments done on gouge of varying thickness that the transition to displacement along Y fractures occurs is not as a function of displacement, but as a function of shear strain within the zone. Thus, at this time, based upon larger displacements than were previously available, it appears that a sequence of fabric development may be recognized and this may be correlated to the amount of shearing strain. Significantly, at relatively large amounts of shearing strain the site of displacement is expected to shift to the boundary-parallel Y fractures. At this stage it is expected that the site of displacement will shift from inside the gouge zone to the interface with the country rock and back again. Future studies will be devoted toward assessing the variation of this fracture array with the previously mentioned parameters.

Calcite fabrics in shear zones. Characterization of textural and fabric changes in simulated gouges of calcite continued as a function of temperature (25° to 910°C) at 200 MPa confining pressure and a shear strain rate of 10^{-2} sec^{-1}. Quantitative evaluation of the textural and fabric changes indicate the following: (1) Three mechanisms of deformation produce the textural and fabric changes in the calcite gouge: (a) cataclasis (including the development of Riedel shears) and some twin gliding at temperatures <250°C where stick-slip occurs, (b) translation gliding (slip) on $\underline{r}$ $\{10\bar{1}1\}$ at all temperatures above 250°C where stable sliding is the displacement mode, producing highly elongated porphyroclasts with strong dimensional and crystallographic orientations, and (c) recrystallization after shearing by slip at temperatures above 600-650°C. (2) A reduction in frictional sliding strength with increasing temperature is primarily due to the well-known, strong, temperature dependence of τ_c for slip on $\underline{r}$ $\{10\bar{1}1\}$. Steady-state stress shortening curves are obtained when the temperature reaches about 600°C, and they work-soften at the highest temperatures. Although it is not known exactly at what degree of shortening the recrystallization takes place, it is clear it does so after significant shear displacement and the accompanying development of highly elongated porphyroclasts. The recrystallization must take place in a matter of ten minutes at most. (3) As detailed previously (Semi-Annual Report, April, 1978), the crystallographic orientation developed during slip tracks the principal strain rather than the stress axes. (4) The recrystallization produces mosaics of neoblasts with axial ratios <2.0 that form at the expense of both porphyroclasts and their fine-grained matrix. Neoblast grain size is inversely proportional to differential stress. (5) Although their axial ratios are <2.0, the neoblasts do show a preferred orientation of long axis that mimic the orientation of the highly elongated pre-existent porphyroclasts. Their crystallographic orientation also is influenced by the fabric produced by slip. (6) From this investigation of textural and structural changes it should now be possible from study of calcite gouge along natural faults to infer the operative deformation mechanisms and corresponding sliding mode, approximate magnitudes of P and T, sense of shear, and the nature of the early history of sliding if succeeded by recrystallization.

Studies of ultrafine simulated gouge material. As part of our studies on simulated gouge materials, we have been investigating the shearing behavior of ultrafine (<1 μm) quartz. The rationale for this is the observation that, during cataclasic behavior of simulated gouge zones, grain size reduction locally continues into the ultrafine range, and subsequent deformation does not continue to decrease the grain size but involves displacements within the ultrafine material. This initial study: (1) compares the behavior of room dry shearing of ultrafine quartz with that of coarser (<100 μm) material, and (2) investigates the effects of water on the behavior of ultrafine quartz of room temperature. Ultrafine quartz powder is prepared by ball milling pure quartz sand and then centrifuging it to separate the oversized grains. The material is spread in layers of 0.3 to 0.8 mm thick along 35° sawcuts in right circular cylinders of Tennessee sandstone and deformed in triaxial compression at an effective confining pressure of 150 MPa. In the case of the wet tests, specimens are confined at 250 MPa and subjected to a pore pressure of 100 MPa. Specimens are normally deformed under a constant shear strain rate of 10^{-2} sec^{-1}, but some wet tests were done at 10^{-3} sec^{-1} where abnormal pore pressures were suspected. In evaluating the effect of grain size, the experimental results show that the finer-grained material leads to: (1) a strengthening of the shear zone and (2) a decrease in the rate of work-hardening in the post-yield region. The observational results show well developed R1 and R2 Riedel shears, but differ in that in the fine-grain material there is very little further grain breakage. This supports the hypothesis that grain size reduction during cataclasis approaches a limiting condition whereby further deformation must take place through intergranular displacements. A comparison of experimental data for dry and wet tests show the behaviors to be identical, suggesting that physico-chemical water weakening effects on quartz material are not significant at room temperature under these strain rates. To assure that any differences between future wet and dry tests may be unequivocally attributed to Rehbinder effects, and not undetected anomolous pore pressures within the shear zone, permeability measurements have been made and pressure decay times calculated. Utilizing the pressure transient method, permeabilities measured at effective confining pressures of 150 MPa are from 10^{-16} to 3×10^{-16} cm^2 for the shear zone-rock system. Values for the rock along range from 10^{-15} to $3 \times 10^{-15} cm^2$. Ultilizing these values, the decay of a pressure pulse in the shear zone as a function of time is made by modifying the heat conduction problem considered by Carslaw and Jaeger (1959). For reasonable values fitting our experiments, it is calculated that it would take 3 sec for an anomalous pore pressure increment to decay to 10% of its initial value. It is concluded that future tests should be conducted at shear strain rate of 10^{-4} sec^{-1} (axial displacement rate of approximately 5×10^{-4} mm sec^{-1}) to ensure complete isolation from anomolous pore pressures. This conclusion is based upon the observation that only stable sliding occurs within simulated gouges under these conditions. The presence of premonitory slip or stick-slip as observed in gouges of other composition would alter the conclusions.

Studies on gouge from U.S.G.S. wells in the San Andreas fault zone. Side-wall cores from depths up to 252 m taken from the U.S.G.S. Dry Valley No. 1 well drilled into the San Andreas fault zone have been examined. Studies have investigated (1) composition, (2) texture and fabric, (3) mechanical behavior, and (4) permeability.

The composition, as determined by x-ray diffraction techniques of four samples is reasonably uniform with 26-33% quartz, 12-17% feldspar, 0-8% kaolinite, 4-8% illite, 9-16% chlorite, and 29-35% montmorillonite.

Microscopic observations show laminated texture of shale and siltstone with the laminae up to 1 cm thick. These are irregular in thickness and discontinuous. Natural fractures cross and offset some textural boundaries, but are terminated at others. Fractures induced by the coring process are very prominent.

Disaggregating the gouge material, and shearing it along a 35° sawcut within Tennessee sandstone at 150 MPa confining pressure, room dry and temperatures to 300°C produce significant differences in behavior. At 25°C sliding is initiated at σ_1-σ_3 of about 120 MPa and is stable. At 300°C the value of σ_1-σ_3 to initiate sliding is raised to about 200 MPa, and the displacement mode changes to stick-slip. Experiments on simulated gouges of chlorite and bentonite deformed under the same conditions show striking similarities.

Whole core permeability measurements at hydrystatic pressures up to 27.5 MPa give values of 45-.4 md., but are influenced by the presense of the coring-induced fractures and should be considered an upper value.

Reports

See Summary of April, 1979.

Magnetic Properties of Rocks Under Non-Hydrostatic Stress

14-08-0001-17702

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Investigations

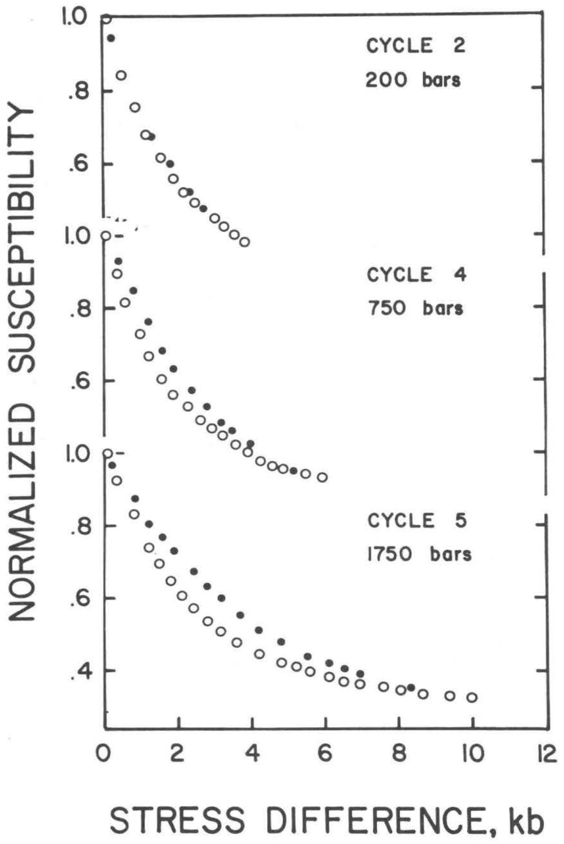
The effect of stress and confining pressure on magnetic susceptibility of rocks during cyclic loading and fracture.

Results

A series of laboratory experiments have been carried out to examine the relationship between magnetic susceptibility, differential stress, volumetric strain and confining pressure during cyclic loading tests to 95 percent of the fracture strength. Five rock types have been tested at confining pressures to 2 kb. Magnetic susceptibility was measured with an a-c bridge apparatus. A 0.5 Oe field was applied parallel to the loading axis of the sample and changes in susceptibility were continuously recorded as the sample was loaded and unloaded.

All the rock types exhibited a similar behavior; increasing stress resulted in a decrease in magnetic susceptibility. The slope of the susceptibility vs stress curve was not constant. It was high for differential stresses below 2 kb and asymptocally approached zero at 9 kb or so. Decreases in susceptibility of 40 to 50 percent at 2 kb were common with a maximum decrease of 60 percent or so at 9 kb. There was some hysteresis on unloading but no permanent demagnetization at the termination of the cycle. The hysteresis was most pronounced on samples loaded to large differential stresses and became progressively smaller as the peak stress for the cycle decreased. Below three kilobars differential stress no hysteresis was observed. Two of the porous rocks, the Dotzero basalt and Mt. St. Helen's andesite failed to show the saturation level at highstress because the strength of the rock at 2 kb confining pressure was on the order of 6-7 kb.

The results of an experiment on the Ralston intrusive are shown in the accompanying figure. Three cycles were carried out at a confining pressure of 200 bars (only the second cycle is shown); the pressure was then augmented to 750 and 1750 bars successively and the fourth and fifth cycle run. At 200 bars confining pressure, the susceptibility decreased by 60 percent as the differential stress was increased to four kilobars. The change in susceptibility was not linear; the rate of change decreased with increasing stress. Upon unloading there was virtually no histeresis. Similarly at 750 and 1750 bars confining pressure the slope of the susceptibility vs stress curve

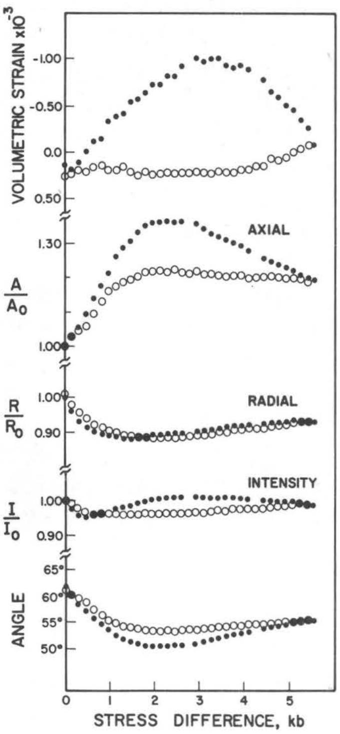


decreased over its entire loading path. In fact, the curve appears to flatten out and asymptologically approach a saturation value of 37 percent of the initial susceptibility at a differential stress of 9 kilobars. The loading curves for the three cycles shown are nearly identical. All exhibit a nearly 60 percent decrease at 4 kilobars differential stress. The unloading curves however are not superposable. It appears that the hysteresis upon unloading increases as the peak differential stress for the cycle is increased. Further experiments are planned to identify the reasons for the unloading hystersis.

The validity of this type of cyclic experiment is justified in two ways. First, there is no permanent demagnetization at the termination of a cycle and second, the effect of confining pressure on susceptibility is minimal. The change in initial susceptibility between 0 and 1500 bars was less than two percent, appreciably smaller than the changes observed during nonhydrostatic loading.

These results indicate that the observed changes in magnetic susceptibility due to differential stress and are not strongly influenced either by confining pressure or crack porosity. Further experiments over a broader range of confining pressures and on all the rock types employed in the remanent magnetization study are planned to determine whether or not this is a universal characteristic of magnetically strong rocks. Specifically, it is of primary interest to determine whether or not the hysteresis upon unloading is in any way related to microcracks in the rock. Furthermore, it is not yet clear what determines the saturation stress level (the stress at which the slope of susceptibility curve is zero); several possibilities such as composition, grain size and structure of the magnetic grains must be examined.

It is of interest to compare these results with those obtained for the same rock types in the remanent magnetization study. Figure 2 exhibits the results of a cycle of the Ralston intrusive tested at 500 bars confining pressure. The volumetric strain, normalized axial (A) and radial (R) components of the magnetic vector as well as the remanent intensity and angle of the magnetic vector with respect to the loading axis are plotted as a function of differential stress. Since the susceptibility measurements described above are most sensitive to changes parallel to the axis of loading, comparison of the changes in the axial component of the magnetic vector seems appropriate. In Figure 2, the seventh stress cycle for the



Ralston intrusive is given. The axial component increased by 30 percent at a point coincident with the onset of pronounced dilatancy. With further loading to the peak stress, the magnetization began to decrease. At the completion of the cycle there was no permanent demagnetization at the conclusion of the first stress cycle; subsequent cycles displayed progressively less permanent demagnetization. While the axial component of the magnetic vector in the Ralston increased with initial loading, that of another suite of rocks characterized by a gabbro decreased. In fact the axial component decreased over the entire portion of the stress cycle. The only apparent effect of increasing crack porosity was a slight increase in the slope of the axial magnetization vs stress curve.

Both the Ralston intrusive and the gabbro have nearly the same titanomagnetite content in the magnetic minerals as indicated by Curie temperature. Furthermore, the magnetic grain sized in both rocks were on the order of 200 μm. The only significant difference was that ilmenite lamellae divided the magnetic grains in the Ralston along (100) whereas the gabbro grains were divided along (111). In spite of the basic differences in behavior with cyclic loading exhibited in remanent magnetization, the effect of stress on susceptibility for these rocks is strikingly similar. The reason for this is not at all clear, but it is apparent that the stress dependence for the two types of magnetization has different mechanism. The remanent behavior is most likely controlled by the microstructure of the magnetic mineralogy whereas the susceptibility may be controlled by composition, grain size, etc. Further studies are underway to delineate the possible mechanism.

In terms of earthquake precursory phenomena, the results suggest that there is not a single typical magnetic response but rather any magnetic change will be strongly dependent on the microstructure of the magnetic mineralogy and the in situ stress level. For example, in a region with a behavior exhibited by the Ralston intrusive where the initial remanent intensity and initial susceptibility are nearly equal, a small magnetic change would be anticipated if the local stresses were less than a kilobar or so because the increase in the axial component of the remanent vector would be somewhat cancelled by the decrease in susceptibility. On the other hand, assuming the inducing field was parallel to the stress axis, if the stresses were high both susceptibility and remanence decrease and therefore should produce a detectalbe change in magnetization. In the case of an area typified by the gabbro, both the remanence and susceptibility decrease over the entire stress range and a detectable change should be observed regardless of stress level. In short, each area will be unique and samples from the region where magnetic surveys are conducted will have to be tested in the laboratory and correlated with any observed precursory magnetic changes.

FUNDAMENTALS OF DEFORMATION AND RUPTURE PROCESSES IN POROUS GEOLOGICAL MATERIALS

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Investigations:

1. Constitutive relations for inelastic rock deformation and rock friction (M. Kachanov, J. R. Rice, A. L. Ruina)

2. Models for the inception of rupture and stability analyses of fault motion (J. R. Rice, J. W. Rudnicki [Univ. of Ill.], D. A. Simons)

3. Mechanisms of tectonic loading. Viscoelastic lithosphere/asthenosphere coupling and associated stress transfer along seismic belts (F. K. Lehner, J. R. Rice, V. C. Li)

4. Field alterations associated with faulting (J. R. Rice in collaboration with J. Walsh [M.I.T.])

Results:

1. In work on constitutive equations for rocks undergoing brittle microfracturing (M. Kachanov, J.R. Rice) the rock is modelled as an elastic material containing an array of penny-shaped cracks. These may be associated with failed grain boundaries of typical sizes 0.5 to 2 mm. When the compressive stress is high enough, frictional sliding begins and the local stress concentrations cause the growth of secondary cracks. The extent of the secondary cracking is controlled by the fracture toughness K_{IC} for microcrack growth. An approximate solution, relating local K_I values to the applied macrostresses and to the geometry of the crack configuration has been developed. This represents the three-dimensional situation at the crack edge by a set of two-dimensional sections, and employs recent results of Cotterell and Rice [1] for the stress analysis of slightly curved or kinked cracks. The expressions contain $\tau-\mu\sigma$ and σ' as loading parameters where τ and σ are the resolved shear and normal stresses on the main crack, σ' is the stress normal to the secondary crack, and μ is the friction coefficient. Results for slip on the main cracks, and openings of secondary cracks, are used together with a procedure for averaging over all crack orientations to predict the resulting macroscopic

inelastic strains. This leads to incremental stress-strain relations in the form $d\varepsilon_{ij} = H_{ijk\ell}(\underset{\sim}{\sigma})d\sigma_{k\ell}$ where $\underset{\sim}{H}(\underset{\sim}{\sigma})$ is the incremental modulus tensor. The relations include dilatancy, stress-induced anisotropy, and a tendency toward strain softening. Further, for a wide range of stress paths the resulting $\underset{\sim}{\varepsilon}$ versus $\underset{\sim}{\sigma}$ relations are path independent. In plasticity terminology, this means that there is a "vertex-like" structure to the yield surface in stress space, and consequent reductions of the incremental stiffnesses, associated with abrupt changes in loading direction, are known to be important in favoring localization bifurcations of the shear band type.

The most recent work has examined the time-dependent constitutive response that results when secondary crack growth is of the stress corrosion type. In this case the experimental results of Atkinson [2] on SCC in various rock types have been used to relate local K_I values to the speed of secondary crack enlargement. Calculations to date show that when the rock has been loaded beyond the onset of secondary cracking, based on K_{IC}, the initial stage of crack growth is very rapid (K_I drops to 60-70% of K_{IC} within a fraction of a second) but decelerates rapidly as K reduces to levels of the order of 30-40% of K_{IC}, perhaps coincident with an effective threshold for growth. Results of these studies will be reported in a Ph.D. thesis by Kachanov, now in preparation.

The studies on constitutive relations for rock friction (A. L. Ruina, J. R. Rice) are based, at present, on an internal variable which characterizes the state of asperity contacts. This variable, θ, is identified with the average contact lifetime and $\dot{\theta}$ is related to the slip rate $\dot{\delta}$. The simplest, but not wholly adequate, relation is [3] $\dot{\theta} = 1-\theta\dot{\delta}/d_c$ where d_c is Dieterich's [4] characteristic slip distance (typically in the range of 1 to 20 μm for polished rock surfaces) and the shear strength is given in the form $\tau = \mu(\theta)\sigma$ where $\mu(\theta)$ is determined by stationary contact experiments [4]. The formulation gives results for τ versus δ which are qualitatively in accord with those observed [4] following sudden changes in slip rate. However, it appears that a viscosity effect must be included in the τ-δ relation to represent the transient strength increase, before the long-term strength drop, in experiments with a sudden change in slip rate.

Currently, Ruina is collaborating with J. Dieterich of USGS in experiments, conducted in Dieterich's laboratory, intended to guide the development of constitutive relations for slip. These are being carried out in a scaled-down version of the sandwich-block apparatus, and Ruina has designed a servo-control system to control the effective stiffness of the loading apparatus. The aim is to study strength degradation during small amounts of frictional slip, in circumstances which would normally lead to stick slip instabilities.

2. The work on constitutive relations outlined above is supportive of the larger effort on the formulation of models for fault instability and for time-dependent inelastic deformation processes that are precursory to rupture. Two papers [5,6] based on our earlier work on this topic have been published in the current reporting period; the latter [6] includes quantitative estimates of the time scale of accelerating precursory deformation that arises from mechanical coupling between pore fluids and a rock mass containing a strain weakening zone that is stressed toward instability. Also, Rice has recently completed a survey [3] of theoretical mechanics analyses of earthquake rupture, the greatest portions of which are devoted to fracture processes and instability models. This includes new results on the estimate

of effective shear fracture energies for large scale confined slip events, based on slip weakening data from dynamic stick slip and quasi-stable fractures of small laboratory specimens. Data for the latter from results of Rummel et al. [7], for example, was shown to lead to fracture energies in the range of 10^4 to 10^5 J/m^2 under confining stresses in the kilobar range. Other new results pertain to tendencies for configurational instabilities of rapidly propagating shear ruptures, due to off-plane stress intensifications as limiting speeds (C_R,C_S) are approached, to effects of discontinuous rupture propagation on conventional estimates of stress drops, and to the effects of fault plane dilatant opening on increasing the effective fracture energy for quasi-static shear fault propagation in fluid infiltrated solids.

Rice and J. W. Rudnicki (of Univ. of Ill.) [8] have recently established conditions for "discontinuous" modes of bifurcation of previously homogeneous inelastic deformation into a shear band; these modes involve continued inelastic deformation within the band and elastic unloading outside it at the bifurcation point. They show that for a very general class of inelastic constitutive relations such modes become possible only when conditions for a "continuous" bifurcation, involving continued inelastic deformation both inside and outside the incipient band, are met and, further, that this continuous bifurcation point sets the lower limit to the range of deformations over which discontinuous bifurcations can occur.

D. A. Simons (at R D Associates, Marina del Rey since Sept. 1979) continued his investigation into the stability of frictional slip along fault planes. This has led to a tractable one-dimensional formulation of stable or unstable fault spreading for arbitrary displacement dependent friction [9]. An adaptable one-dimensional model for sliding in a displacement-controlled, direct shear configuration is derived and applied to study the quasi-static spreading and ultimate instability of bounded slip zones. Hamilton's principle shows that if the approximate displacement in the sliding blocks vary linearly with distance from the interface, but arbitrary along it, then the slip δ satisfies a forced telegraph equation (a wave equation plus a constant multiple of slip). The coefficients depend explicitly on the thickness, density, and stiffness of the blocks, and the forcing is the excess of the boundary shear over the local frictional resistance. The friction is assumed to drop linearly from the peak strength τ_p at $\delta=0^+$ to the residual level τ_r when $\delta \geqslant \delta_c$. A preassigned weakness zone is introduced, with the weakness due either to locally depressed peak strength or to residual stress caused by a lag in the previous slip (seismic gap). Explicit solutions are obtained for the boundary shear increases, instability (defined here as infinite incremental slip or spreading with finite incremental boundary displacement) eventually occurs in all cases, but its nature depends on the relative softening rates of the friction law and the surroundings. For stiff surroundings, instability is delayed until the boundary shear reaches the peak strength τ_p and the slip zone has spread infinitely far. But for soft surroundings, the more representative case for a geophysical setting, instability occurs after finite precursory spreading, and at a level of boundary shear which may only slightly exceed the residual friction level τ_r .

3. An important complement to our studies of rock deformation and fracture behavior and related models of fault instability are investigations into the nature of the mechanism of tectonic loading as the ultimate cause of earthquake ruptures. A mechanism has been analyzed in recent work of F.K. Lehner, V.C. Li and Rice which may be fundamental

to observed spreading and migration of seismic activity, in particular of large earthquakes, along plate boundaries or other seismic lineaments [3,10]. It operates when an elastic lithosphere is coupled dynamically to a visco-elastic (Maxwellian) asthenosphere. The coupling is assumed to be of the same type as in Elsasser's plane stress plate/foundation model, generalized however so as to allow for viscoelastic response of the foundation. A further kinematic approximation then yields a differential equation in only one relevant thickness averaged displacement component, permitting analytical solutions for the time-dependent quasi-static stressing associated with steadily propagating or suddenly-introduced slip zones or zones of stress drop, both along transform and subduction type boundaries. Speed dependent stress attenuation ahead of steadily propagating crack-like zones of stress drop is predicted as shown in Figure 1. Similarly, a time-dependent rise in stress level ahead of suddenly-introduced ruptures (seen as zones of constant stress drop) is found and apparent from the solution plotted in Figure 2. These results permit a first assessment of the potential significance of viscoelastic coupling effects in setting a time scale for values of stress transfer onto segments of a plate boundary which border new ruptures, and may thus become the site of a subsequent event. From Figure 1 it is apparent that viscosities of 5×10^{19} and higher would allow for significant stress attenuation of speeds comparable with suggested average rates of advance of epicenters of large earthquakes. Leaving open the question of any persistent tendency towards epicenter migration, we conclude that consecutive rupture events exhibiting an average rate of typically 100 km/yr fall well into the range of significant viscoelastic coupling effects. Individual earthquakes may in fact be linked to triggering disturbances which travel aseismically at higher than average epicenter migration speeds and, when arrested by them, are capable of attacking barriers or "gap zones" through progressive transfer of load from a relaxing asthenosphere. The available ultimate build-up in stress can be read off Figure 1 as the difference between the graphs for V=0 and for the actual propagation speed of the triggering zone of stress drop just before its arrest. Triggering disturbances of this kind, perhaps consisting of a series of fast creep events which progressively lower the stress along a fault segment impinging on some barrier, may gain significance as preminotory signals once a barrier has been identified. From Figure 2 the stress alteration ahead of a suddenly-introduced through-lithosphere rupture may be read off for various times. This solution permits a quantitative estimate of the actual times involved in the reloading of the lithosphere by the relaxing asthenosphere, following a sudden rupture or sudden arrest of a propagating zone of stress drop. The times are well within the range of recurrence time, reported for large gap-zone filling earthquakes.

4. In previous work [11], J. B. Walsh (of M.I.T.) and Rice developed a technique based on the elastic reciprocal theorem for calculating changes in gravity fields near the earth's surface due to fault motion at depth. Currently they are working on an extension of this technique to the case of magnetic field alterations due to faulting in rock masses containing magnetized grains. A similar application of the reciprocal theorem shows that effects due to faulting can be calculated in terms of the stress state induced in an unfaulted half space when an infinitesimal magnetic dipole is placed at a point near its surface and oriented in a direction for which the field changes are to be calculated. Continuing work is directed toward a formulation of magneto-elastic coupling [12], appropriate for natural rock masses, so that the requisite stress field can be calculated.

References:

1. B. Cotterell and J.R. Rice, Int. J. Fracture - in press (1979).
2. B.K. Atkinson, Int. J. Rock Mech. Min. Sci. 16, 49 (1979); Pure Appl. Geophys. - in press (1979).
3. J.R. Rice, "The mechanics of earthquake rupture," Proc. Int. Sch. Physics "Enrico Fermi", 1979 Course on Phys. of the Earth's Interior, ed. E. Boschi, North Holland - in press (1979).
4. J.H. Dieterich, J. Geophys. Res. 77, 3690 (1972); 84, 2161 (1979); 84, 2169 (1979).
5. J.R. Rice, Gerl. Beitr. Geophys. 88, 91 (1979).
6. J.R. Rice and J.W. Rudnicki, J. Geophys. Res. 84, 2177 (1979).
7. F. Rummel, H.J. Alheid and C. Frohn, Gerl. Beitr. Geophys. 88 (1979).
8. J.R. Rice and J.W. Rudnicki, Int. J. Solids Structures - in press (1979).
9. D.A. Simons, EOS 59 (12), 1204 (1978).
10. F.K. Lehner, V.C. Li and J.R. Rice, to be presented at AGU Fall Meeting, San Francisco (1979); manuscript in preparation.
11. J.B. Walsh and J.R. Rice, J. Geophys. Res. 84, 165 (1979).
12. W.F. Brown, Jr., "Magnetoelastic interactions," Springer Tracts on Nat. Phil., Vol. 9, Springer-Verlag (1966).

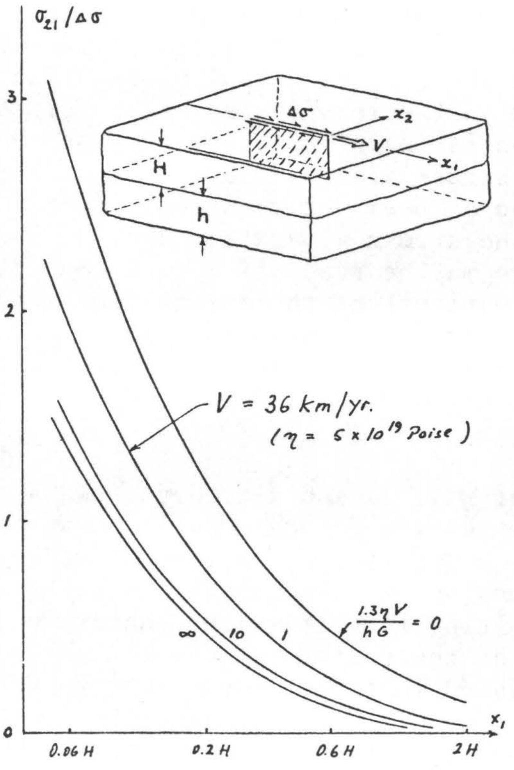


Fig. 1 - Stress ahead of zone (length 2H) of constant thickness averaged stress drop $\Delta\sigma$, travelling along transform boundary at various speeds V .

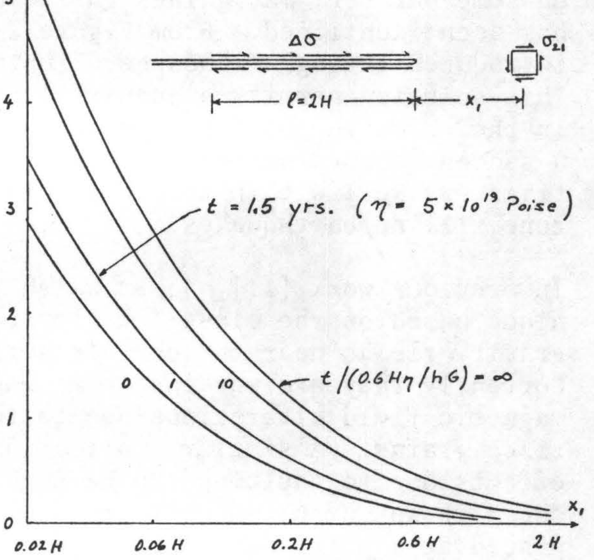
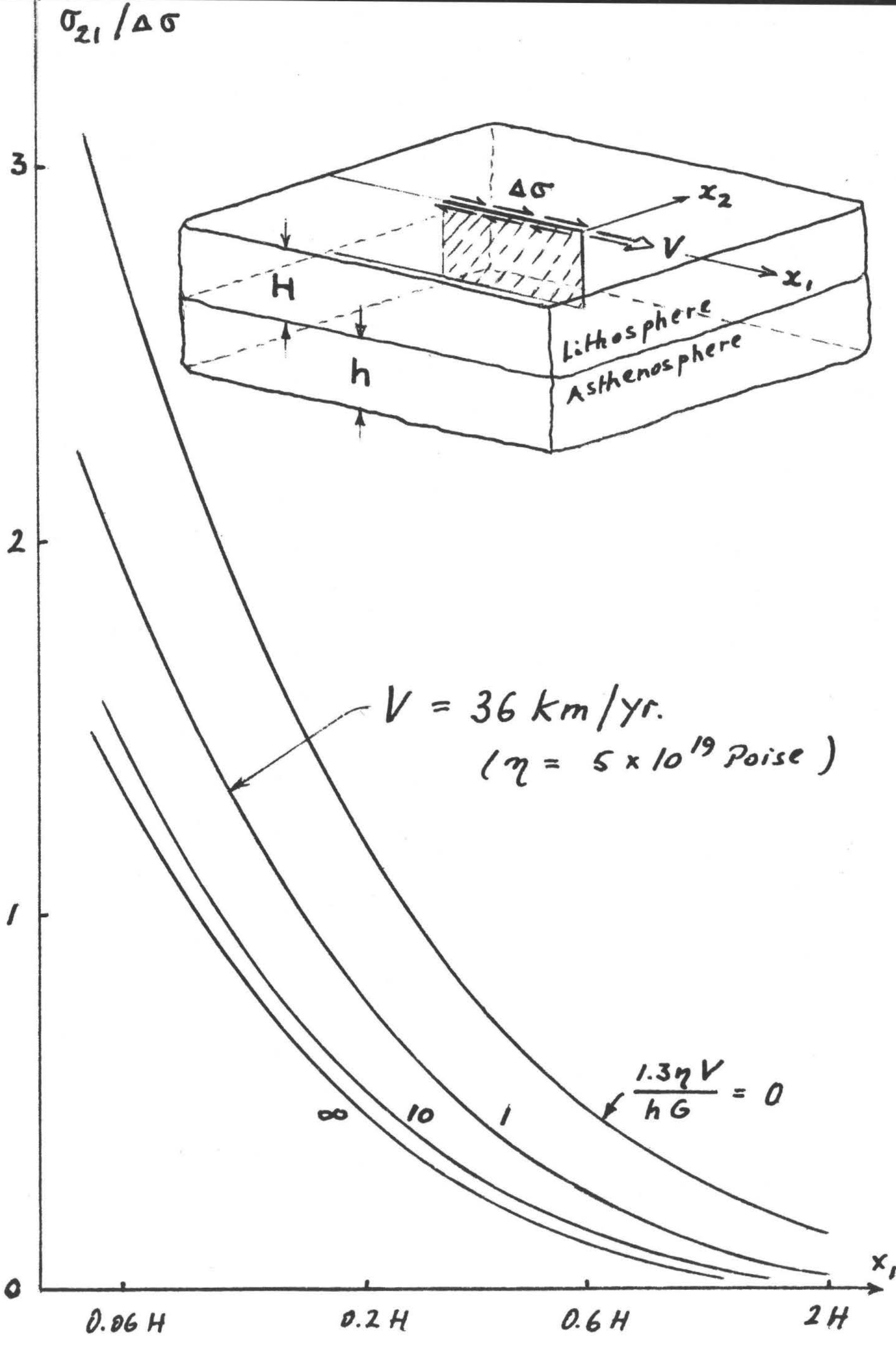


Fig. 2 - Stress on transform boundary following sudden stress drop $\Delta\sigma$.



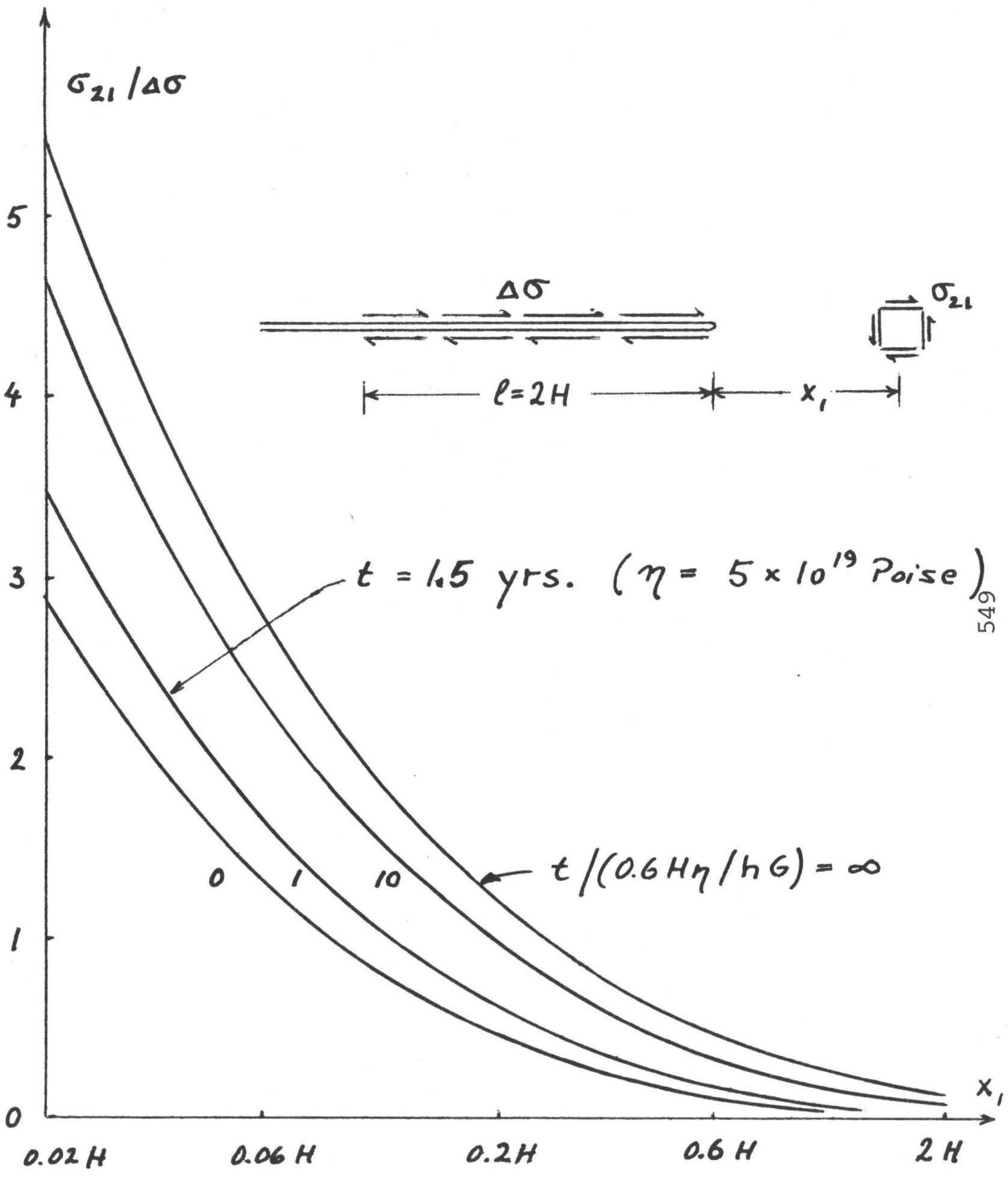


Fig. 1 - Stress ahead of zone (length 2H) of constant thickness averaged stress drop $\Delta\sigma$, travelling along trans-

Fig. 2 - Stress on transform boundary following sudden stress drop $\Delta\sigma$.

AN EXPERIMENTAL STUDY OF THE RHEOLOGY OF CRUSTAL ROCKS

Contract 14-08-0001-15247

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401-863-2240

The purpose of this study is to gain a more fundamental understanding of the deformation of crustal rocks by determining the grain-scale deformation mechanisms operative at different pressures, temperatures, strain rates, differential stresses, and water contents; to determine both the macroscopic and the microscopic brittle-ductile transitions for these rocks as a function of these variables; and to develop an understanding of the rheology of polyphase aggregates in terms of the flow properties of their principal constituents which will allow extrapolation to natural conditions. Our approach involves detailed petrographic and transmission electron microscope (TEM) analysis of the deformed samples.

During this past year we have submitted three manuscripts dealing with the role of water in crustal deformation, one manuscript on the brittle-ductile transition and grain-scale deformation mechanisms operative in experimentally deformed diabase, anorthosite, and clinopyroxenite, and we have completed creep experiments on a number of polyphase rocks and their constituents and have begun theoretical work on a flow law for polyphase aggregates. Our results are summarized below.

Effect of Water on Crustal Deformation

A pressure dependence of hydrolytic weakening has been inferred from nominally 'dry' deformation experiments on a fine-grained granite, an aplite, a quartzite, and an albite rock (Tullis, Shelton, and Yund, 1979). For all four rock types deformation at lower temperatures, where microcracking contributes to the deformation, results in higher yield strengths for samples deformed at higher confining pressure, as expected. As the temperature is increased and the proportion of microcracking to that of dislocation glide and climb diminishes, the difference in strength between samples deformed at low and high confining pressure diminishes and becomes zero at a temperature that depends somewhat on the material. However at even higher temperatures there is an inversion of the strength dependence on pressure, and samples deformed at higher confining pressure are weaker. We believe this is due to a pressure effect of hydrolytic weakening: the recovery rate associated with the dislocation glide and climb process is dependent on the concentration of water in the structure, and the concentration of water (which diffuses into the structure from grain boundaries and fluid inclusions even in nominally 'dry' samples) increases with confining pressure.

We have studied the effect of water on deformation in the brittle-ductile transition region for both Westerly granite and the Hale albite rock by doing 'wet' experiments (a trace of water is sealed inside the Pt capsule with the sample) at a variety of temperatures, pressures, and strain rates (Tullis and Yund, in press). We found that there was a change in the nature of the sample deformation with increasing strain during any given run, as the water gradually diffused into the crystal structure; the earlier deformation was more brittle but it became more ductile as greater amounts of water penetrated. We have used optical and TEM observations of the deformed samples to assess the effect of the water on the brittle-ductile transition, and find that the net effect of the water (allowing time for it to penetrate the structure) is to reduce the temperature of the transition from microcracking to dislocation glide and climb by about 150°C, for both quartz and feldspar. We also found that samples deformed 'wet' at 10 kb confining pressure show less hydrolytic weakening than do samples deformed 'wet' at the same temperature at 15 kb, in agreement with the inferences of Tullis et al. (1979). We presume this is because there is a lower equilibrium concentration of water in the structure at lower pressure.

We have also studied the effect of water on the diffusional interchange of Si-Al, in part because this may be the rate limiting species for high temperature creep of silicates. We have done this by studying the kinetics of ordering and disordering of Si and Al in Hale albite (Tullis and Yund, 1979; Yund and Tullis, in press). We found that for a given water content, the rate of disordering is increased by an increase in confining pressure; that for a given confining pressure the rate of disordering is increased for an increase in water content; and that for any given pressure and water content, the rate of disordering is increased if the sample is plastically deformed. We interpret these results to mean that water directly increases the rate of Al-Si interchange and that more water enters the structure and is thus available to aid this process at higher pressure. Furthermore, the interchange occurs more easily in the disturbed region around dislocation cores and thus is especially important to the overall kinetics when the dislocations are actively moving through the crystal. This is the first time that strain-enhanced diffusion has been demonstrated in a mineral.

The results of the above studies have important implications for crustal deformation. It is not at all a simple matter to extrapolate flow laws determined experimentally to deformation in the crust. We know that water content, which itself depends on pressure and temperature, profoundly affects the flow properties, and for any given material there are probably many different flow laws which are pertinent for different water contents. However, we do not have data on the water contents of either experimentally or naturally deformed rocks. Furthermore, depending on their history, naturally deformed rocks may not contain an equilibrium amount of water, thus making it even more difficult to know what flow law is appropriate. However, a number of useful points have emerged from our study of the effect of water to date. It appears that the concentration of water in the crystal structure of silicate minerals increases with pressure. The proportion or ease of dislocation glide and climb at a given temperature increases with increasing water content. The way in which water affects this process is apparently through its role in affecting the self-diffusion of various species. Previous work has shown that water increases the rate and decreases the activation energy for oxygen self-diffusion, and furthermore that the rate increases with increasing fluid pressure. We have now shown that water also increases the rate and decreases the activation energy for diffusional interchange of Al-Si. Because the activation energy for Al/Si is higher and the rate is slower than for O, it appears that for feldspar at least, which is volumetrically the most important mineral in the crust, Si-Al may be the rate controlling species for high temperature creep.

Deformation Mechanisms of Diabase and its Constituents

We have performed deformation experiments on Maryland diabase over a wide range of temperatures and pressures; for comparison we have done a number of experiments on monomineralic aggregates of its constituents, plagioclase and clinopyroxene, at the same conditions. We have completed a manuscript (Kronenberg and Shelton, in press) detailing the macroscopic brittle-ductile transition for these materials as well as the grain-scale deformation mechanisms operative in each phase over the whole range of conditions, and the contribution of each phase to the sample strain. We find that for an experimental strain rate of 10^{-6}/sec, for deformation at lower temperatures (600-800°C) where the plagioclase deforms by microcracking and the pyroxene by mechanical twinning, the pyroxene is the weaker phase. However, at higher temperatures (900-1000°C) where both phases deform by mechanical twinning and dislocation glide and climb, the plagioclase is the weaker phase. Extrapolating to the slower geologic strain rates, plagioclase is likely to be the weaker phase for all natural ductile deformations. Thus the deformation of gabbroic rocks will be controlled in part by their texture; if they consist of an interconnected framework of plagioclase laths with isolated pyroxene grains, as does the Maryland diabase, then the deformation of the rock will be principally controlled by that of the plagioclase member.

Flow Laws for Polyphase Aggregates

Fine-grained, monomineralic aggregates of albite, labradorite, and clinopyroxene, as well as the bi-mineralic diabase, have been deformed in the creep mode under a constant differential stress of 3 kb, at a confining pressure of 15 kb. The temperature dependence of the strain rate for each material is obtained by lowering the temperature in steps from 1100 to 850°C and recording the resulting steady state strain rate at each step. Activation energies (neglecting activation volume) thus determined are 55 kcal/mole for albite rock, 60 kcal/mole for anorthosite, and 79 kcal/mole for clinopyroxenite, and the apparent activation energy for the diabase is 63 kcal/mole. The near match of the temperature dependence for the anorthosite and the diabase lends support to the idea that the interconnected plagioclase network controls the deformation of the diabase (Kronenberg and Shelton, 1978; Shelton and Kronenberg, 1978).

These experiments were all performed on samples dried on a hot plate at 160°C; the samples contained approximately 0.1% water by weight. Samples of the same clinopyroxenite, but with more of the water removed by drying at higher temperature, were deformed by Kirby and Kronenberg. They obtained an activation energy of 106 kcal/mole. There is thus a large difference in activation energy between samples of the same rock which differ only in a trace amount of water. In fact, the difference between 'wetter' and 'drier' samples of the same mineral is greater than the variation between different crustal minerals of roughly the same water content. Experiments are currently underway to verify this effect for the albite rock.

As a rough generalization, the deformation of a polyphase rock should be controlled by the deformation of its weakest interconnected phase. However this is only a first approximation, and the strength and volume fraction of the stronger, isolated phases can also be important. Chen and Argon (1979) have treated this problem for a model of homogeneously distributed spheres of one rheology in a matrix of a different rheology, using the self-consistent theory for non-linear deformation of composites. A numerical solution will yield the effective stress exponent for a composite if the flow parameters and volume fractions of the constituents are known. We plan to use the experimentally determined flow parameters for plagioclase and pyroxene, their volume fractions in the diabase, and the above model to determine a theoretical flow law for the diabase. The law will then be compared with experimental results from diabase deformation. This should be a useful way to model the behavior of many polyphase crustal rocks.

Reports

Kronenberg, A.K., and Shelton, G.L., 1978, Transmission electron microscopy of experimentally deformed Maryland diabase, Trans. Amer. Geophys. Union, v. 59, p. 1186.

Kronenberg, A.K., and Shelton, G.L., in press, Deformation microstructures in experimentally deformed Maryland diabase, Jour. Struc. Geol.

Shelton, G.L., and Kronenberg, A.K., 1978, Experimentally determined relationship between single and polyphase aggregate strengths, Trans. Amer. Geophys. Union, v. 59, p. 1185.

Tullis, J., and Yund, R.A., 1979, Albite disordering: effect of water content, pressure, and strain, Trans. Amer. Geophys. Union, v. 60, p. 420.

Tullis, J., and Yund, R.A., in press, Hydrolytic weakening of experimentally deformed Westerly granite and Hale albite rock, Jour. Struc. Geol.

Tullis, J., Shelton, G.L., and Yund, R.A., 1979, Pressure dependence of rock strength: implications for hydrolytic weakening, Bull. Mineral., v. 102, p. 110-114.

Yund, R.A., and Tullis, J., in press, The effect of water, pressure, and strain on Al/Si order-disorder kinetics in feldspar, Contrib. Mineral. Petrol.

Rock Mechanical Investigation of Clay and Clayey Gouge at High Pressures and Temperatures

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Investigations

1. The mechanical properties of fault gouges from the deep San Andreas fault zone are investigated at high pressures. Compressibility and acoustic velocities are measured up to 2 kb. The mechanical properties are studied under triaxial loading and in pure shear.

Results

1. SOME PHYSICAL PROPERTIES OF FAULT GOUGES AT HIGH PRESSURE: Several types of physical properties of saturated fault gouge, including the velocity of compressional waves, isothermal incompressibility , and electrical resistivity are determined at high pressures, under drained and undrained conditions. The velocities of compressional waves in the gouge increase from 1.9 km/sec at low pressure to 2.2 km/sec at P = 2kb. The low-pressure values are in good agreement with the velocities measured in situ. The isothermal incompressibility of the fault gouge increases with pressure from about 30 kb at 1 atm to 124 kb at 2 kb. The electrical resistivity increases with pressure from 30 ohm-m at low pressure to 150 ohm-m at 1 kb. All these properties are vastly different from the properties of rocks in general and may be responsible for some of the characteristics observed for fault zones.

2. FRICTIONAL PROPERTIES OF SATURATED GOUGES FROM THE SAN ANDREAS FAULT ZONE: The effect of saturated fault gouges of various kinds (from the San Andreas fault zone) on frictional sliding is investigated at high pressure, under drained, triaxial condition. In general, the magnitude of shear stress required to cause sliding on rock joints filled with saturated fault gouges is very much lower than that required to cause sliding on clean rock joints or on joints filled with dry clays or crushed rocks. Fault gouge with distinct grain-size distributions affects frictional sliding in distinctly different ways. In general, normally consolidated silt-clay gouge which is characterized by a complete lack of sandy component shows a significantly lower shear resistance to frictional sliding than a sandy fault gouge under the same condition. Furthermore, the silt-clay gouge shows little strain-hardening after yielding, in contrast to the strong strain-hardening following yielding in a sandy fault gouge. Since fault zones are typically very inhomogeneous, our experimental results imply that the strength of a fault can not be spatially uniform.

Digital Signal Processing of Seismic Data

9930-02101

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Investigations

1. Space-time patterns of seismic activity and earthquake source directivity were correlated with fault trace discontinuities to develop and test a model of the structure and failure process for the creeping sections of faults in central California.

2. Published body-wave corner frequencies were examined to test significance of corner frequency estimates for earthquake source parameter determination.

Results

1. On January 15, 1973, a magnitude M_L 4.1 earthquake occurred near Cienega Road on the San Andreas fault about 20 km south of Hollister, California. A 3-km-long segment of the fault southeast of the earthquake was aseismic for the seven weeks preceding the event, although microearthquakes occurred at both its ends. The first day's aftershocks occurred at the northwest end of the aseismic segment; later aftershock activity migrated to the southeast, filling the remainder of the segment. If the discontinuous surface trace of the fault can be extrapolated to the focal region of the earthquakes to define fault geometry at depth, then aftershocks occurred primarily on one continuous segment of the fault, and epicenter locations and direction of rupture propagation (inferred from the azimuthal pattern of P-wave radiation) of the precursory shocks correlate with the discontinuities in the trace that terminate the segment. The 1970-76 deficit in seismic slip within the segment suggests that fault creep accounts for a significant part of cumulative slip within the segment. The pattern of seismicity is consistent with the hypothesis that creep on the segment before the mainshock caused a buildup of stress at the ends of the segment or at the ends of adjacent offset segments. Correlation of seismicity and discontinuities or bends in the mapped fault trace are the basis for an extension and refinement of the "stuck" and "creeping" patch model of the San Andreas fault in central California. Patch boundaries extend from the free surface down through the seismogenic zone. Creeping patches lie beneath smooth continuous segments of the fault trace. Stuck patches lie beneath discontinuities or bends in the fault trace.

The M_L 5.9 (BRK) Coyote Lake earthquake of August 6, 1979 occurred on a creeping section of the Calaveras fault about 10 km north-northeast of Gilroy, California. Epicenters of early (first 15 days) aftershocks lie primarily along a 16-km-long, relatively continuous segment of the fault trace. The main shock was located near a right-stepping offset in the fault trace that terminates the segment on the northwest. Aftershocks concentrate near a mapped complication in the trace near the center of the segment and at a right-stepping offset at the southeast end of the segment. Although the Coyote Lake segment was not preceded by prominent foreshock activity, a preliminary analysis of seismic activity on the Calaveras fault near the Coyote Lake earthquakes shows that cumulative seismic slip in the decade before the sequence was concentrated near the right-stepping fault trace offsets at the ends of the segment. There appears to be persistent seismic activity near the fault trace complication near the center of the segment. Clearly the seismic activity associated with the Coyote Lake earthquake can be rationalized in terms of the fault model developed for the Cienega Road shock. Seismic activity (epicenters and directivity) associated with the 1934 and 1966 Parkfield sequences, the 1971 Limekilm Road swarm, the 1972 Bear Valley sequence, and the 1972 Stone Canyon sequence (all on the San Andreas fault) as well as the felt shocks on August 29, 1978 east of San Jose on the Calaveras fault correlates with mapped fault trace discontinuities consistent with the proposed model.

2. There is a systematic difference in the magnitude dependence of P- and SH-wave corner frequencies for Bear Valley earthquakes that can be explained using simple dislocation models if the usual assumption of similarity (see Aki, 1967) is relaxed, e.g., if rupture-propagation velocity increases with source size from 0.6β for $M \simeq 2$ to 0.9β for $M \simeq 4$, Relaxation of similarity has profound implications for the interpretation of body-wave data in terms of earthquake source parameters. In relating their scaling model for 1965 Rat Island earthquakes to shocks on the San Andreas fault in central California, Frasier and North (1978) ascribed systematic differences in the magnitude dependence of the corner frequencies they inferred from the data of O'Neill and Healy (1973) and the corner frequencies of Johnson and McEvilly (1974) to the fact that O'Neill and Healy's were measured in the time domain and Johnson and McEvilly's in the frequency domain. A likelier explanation is that the difference is a function of P-wave relative to Love-wave measurements, since O'Neill and Healy's P-wave data are consistent with the P-wave corner frequencies of Bakun et al. (1976).

References Cited

Aki, K., 1967, Scaling law of seismic spectrum: Journal of Geophysical Research, v. 72, p. 1217-1231.

Bakun, W. H., Bufe, C. G., and Stewart, R. M., 1976, Body-wave spectra of central California earthquakes: Seismological Society of America Bulletin, v. 66, p. 363-384.

Frasier, C. W., and North, R. G., 1978, Evidence for ω-cube scaling from amplitudes and periods of the Rat Island sequence (1965): Seismological Society of America Bulletin, v. 68, p. 265-282.

Johnson, L. R., and McEvilly, T. V., 1974, Near-field observations and source parameters of central California earthquakes: Seismological Society of America Bulletin, v. 64, p. 1855-1886.

O'Neill, M. E., and Healy, J. H., 1973, Determination of source parameters of small earthquakes from P-wave rise time: Seismological Society of America Bulletin, v. 63, p. 599-614.

Reports

Bakun, W. H., 1979, Seismic activity associated with the August 6, 1979 Coyote Lake earthquake (abs.): American Geophysical Union Transactions (in press).

Bakun, W. H., Bufe, C. G., and Stewart, R. M., 19 . Do P- and S-wave corner frequencies measure different source parameters?: Seismological Society of America Bulletin (in press).

Bakun, W. H., Stewart, R. M., Bufe, C. G., and Marks, S. M., 1980, Implication of seismicity for failure of a section of the San Andreas fault: Seismological Society of America Bulletin, v. 70, no. 1.

Bufe, C. G., and Bakun, W. H., 1979, Use of spectral ratios to determine seismic attenuation , _in_ Conference on Seismic Wave Attenuation, Stanford, June 25-27, 1979, Abstracts: Stanford University Publications, Geological Sciences, v. 17, p. 33.

Bufe, C. G., Bakun, W. H., and McEvilly, T. V., 1979, Historic seismic activity and the 1979 Coyote Lake sequence (abs.): American Geophysical Union Transactions (in press).

Lee, W. H. K., Herd, D. G., Cagnetti, V., Bakun, W. H., and Rapport, A., 1979, A preliminary study of the Coyote Lake earthquake of August 6, 1979 and its major aftershocks (abs.): American Geophysical Union Transactions (in press).

Statistical Fault Models

9940-02411

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Investigations

1. Develop a method for the synthesis of high frequency ground motion and spectra close to large earthquakes.

2. Develop and apply a hybrid method for generating inexpensive Green's functions for use in the synthesis of ground motions from large, complicated faults.

3. Investigate the source orientation and strength of the April 15, 1979 Montenegro, Yugoslavia earthquake, as a preliminary step before studying the strong motion records.

4. Investigate the scattering of body-to-surface-wave energy to aid in our understanding of the horizontal wavelengths to be expected in strong ground motion.

Results

1. A program was written which computes accelerograms from a propagating line-source in a whole space, with the rupture velocity, dislocation amplitude, and characteristics of the source time-function chosen from statistical distributions. The model includes a causal Q and predicts three components of motion at a site. It was developed as part of a joint effort with W. Joyner and serves as an alternative model which can be used to check the results from his stochastic model.

2. The WKBJ program, written by Chapman, which computes ground motion in a vertically heterogeneous velocity structure has been modified to execute on the PDP 11/70. In addition, the 3 components of ground motion from a shear dislocation at any depth, and the effects of attenuation have been included. The output of the program has been coupled to a program which accounts for all internal reverberations and the effects of attenuation within a stack of low velocity sediments beneath a site. The method leads to an inexpensive way of generating Green's function responses. It is hoped the technique will aid in the modelling of extended sources, where inexpensive computational procedures are desirable.

The Coyote Lake earthquake of August 6, 1979, and the subsequent aftershocks are being modelled using the hybrid technique described above. The emphasis is on the large amplitudes which are generated from S converted to

P at the base of the sediments. The results described here represent independent work being done by Burke Angstman, with minimal supervision by D. Boore.

3. P and S waves recorded on long period WWSSN instruments from the April 15, 1979 Montenegro, Yugoslavia earthquake are consistent with left lateral, reverse faulting on a plane dipping 78° in a direction of 221° clockwise from north or right lateral, reverse motion on a plane dipping 45° in a direction of 119° clockwise from north. The strike of the first plane is almost parallel to the coast, whereas that of the second plane is almost perpendicular to the coast. Neither plane corresponds to the prevalent expectation that Yugoslavia is being underthrust in this region by the Adriatic. Results from H. Kanamori, however, using 250 s waves from the IDA network are consistent with this interpretation. Furthermore, the moment from these ultra long period waves is about 3 to 4 times that found from the WWSSN recordings, which give about 0.9×10^{25} dyne-cm. (This moment corresponds to an $M_s = 2/3 (\log M_0 - 16)$. The NEIS magnitude was 7.0, but a reevaluation of this, taking into account azimuthal biases, makes it seem that $M_s = 6.6$ or 6.7 is more reasonable.) The inconsistency in the orientation and moment is not without precedence and can be reasonably attributed to a complex source process; the different period waves (≈15 sec. for WWSSN and ≈250 s for IDA) are simply seeing different parts of the faulting process. Aftershock locations are widely scattered and give little help in defining the geometry of the fault. Relocation studies are underway, but without local control they may not be very useful. This work is being done by D. Boore, S. Harding, and J. Sims.

4. Scattering of body-to-surface-waves provides a means for converting energy with essentially infinite horizontal wavelength to motion with relatively short wavelengths. This is of interest to engineers who are concerned with the design of structures with large horizontal dimensions, such as pipelines, tunnels, and bridges. A literature survey showed a lack of relevent studies for predicting the efficiency of the scattering. We have studied the conversion process for the simple case of vertically incident SV and P waves impinging on step and ramp changes in surface topography. Scattering to Rayleigh waves is quite pronounced, with a scattering coefficient on the order of 0.4. The coefficient depends on whether the motion is recorded on the upper or lower surface of the cliff and also depends on the wavelength of the incident motion relative to the height of the cliff. S. Harmsen has a key role in this project. He developed the finite difference code being used, and he has made all the computer runs.

Reports

Papers:

Boore, D. M., Joyner, W. B., Oliver, A. A. III, and Page, R. A., 1980, Peak acceleration, velocity, and displacement from strong motion records: Bull. Seism. Soc. Am., v. 70 (in press).

Hudson, J. A., and Boore, D. M., 1979, Comments on "Scattered surface waves from a surface obstacle" by J. A. Hudson: Geophys. Journal (in press).

Savy, J. B., Shah, H. C., and Boore, D. M., 1979, A nonstationary risk model with geophysical input: Journal Structural Div., Am. Soc. Civil Eng., in press.

Abstracts:

Angstman, B. G., and Boore, D. M., 1979, Inexpensive Green's functions: a hybrid approach for the synthesis of body-wave seismograms [abs.]: Earthquake Notes (Seismological Society of America), v. 49, p. 32.

Angstman, B., Spudich, P., and Fletcher, J., 1979, The Coyote Lake earthquake: 0.42 g acceleration from an S-P converted phase [abs.]: EOS (American Geophysical Union, Transactions), in press.

Boore, D. M., 1980, On the attenuation of peak velocity [abs.]: submitted to the 7th World Conference on Earthquake Engineering.

Joyner, W. B., and Boore, D. M., 1980, A statistical source model for synthetic strong-motion seismograms [abs.]: submitted to the 7th World Conference on Earthquake Engineering.

Savy, J. B., and Boore, D. M., 1979, Ground motion simulation for risk analysis [abs.]: Earthquake Notes (Seismological Society of America), v. 49, p. 36.

Spectral and Time Domain Analysis

9930-02105

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Investigations

Two major experiments were conducted this spring and summer:

1. During most of May and early June, we deployed five to six digital cassette recorders around the Monticello reservoir, South Carolina, a site of apparent induced seismicity to obtain spectra from a suite of intraplate earthquakes that would also have relevance to induced seismicity and tectonic stress. Each recording system had a 3-component set of 2 Hz velocity transducers, and each channel was digitized at 200 samples/s by a 12-bit analog-to-digital converter.

2. On August 6, 1979 a mag 5.9 earthquake occurred just 2 to 3 km east of the Calaveras fault near the north end of the Coyote Lake reservoir. Eight digital cassette recorders monitoring four 3-component velocity transducers and four 3-component force balance accelerometers were installed to cover a 14 km segment of the Calaveras fault defined by the main shock at the north and extending south to San Felipe reservoir. Three of the velocity systems were installed to extend from the Calaveras fault to Gilroy crossing the Santa Clara valley to obtain data in the response of alluvium to shaking generated by the aftershocks.

Results

1. Two swarms, each lasting two to three days occurred at the northwestern edge of the reservoir within the recording period. There were 352 events recorded in a 30-day period with 52 on three or more stations. The events are typically between 0 and 2 km deep at the western edge of the reservoir. Corner frequencies range from 10 to more than 100 Hz (determined from one station where the sampling rate was 600 samples/s). They frequently span the range 10 to 40 Hz for a single event suggesting that there is a measure of directivity for these small events (moments are typically about 10^{17} dyne-cm). Initial stereo plots of the corner frequencies suggest that the rupture propagation is away from the reservoir. Further analysis will include calculating moment, stress drop, and source radius and comparing these data to in situ stress data obtained by Mark Zoback, and spectra from Coyote Lake and Oroville, California.

2. There were 167 events recorded in a little over one month; 60 in three or more stations. Preliminary scanning of time domain signals and fourier spectra show several interesting aspects of this data. Three stations form a profile along the fault zone and for aftershocks occurring near the southern end of the array (most of the early aftershock activity was located at the southern end), the signals at two stations north along the fault show a distinctive low-frequency character when compared to recordings at a site not on the fault but at the southern end of the array. As the effect appears to be universal, it is apparently caused by severe attenuation in the fault zone. Spectra suggest the attenuation is diminishing the peak amplitudes of the velocity spectra (the amplitudes near the corner frequency) rather than a progressive decrease in the amplitudes of the high frequencies as would be expected from the normal attenuation law.

Source parameters for a mag=2.5 event recorded at 0.2 km from the fault for P- and S-waves are, respectively; 0.11×10^{20} and 0.73×10^{20} dyne-cm, and 7 and 3.3 bars with decay rate of the high frequencies being typically greater than ω^{-4}.

Reports

Fletcher, J. B., 1979, Corner frequencies and stress drops from broad-band high-dynamic range recordings of aftershocks of the Oroville, California earthquake (abs.): EOS, American Geophysical Union Transactions, v. 60, no. 18, p. 322.

Fletcher, J. B., 1980, Spectra from high-dynamic-range digital recording of Oroville, California aftershocks and their source parameters: Seismological Society of America Bulletin (in press).

Earthquake Source Parameters from Near-Field Observations

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Investigations

1. Records of strong ground motion of mine tremors in a gold mine near Johannesburg and earthquakes in California were analyzed with regard to relating quantities such as peak acceleration and peak velocity to seismic source processes.

2. The geometry of a mine-induced fault zone, which was exhumed in the E.R.P.M. gold mine in 1974 and 1975, was analyzed in terms of fracture mechanics involving interactions between cracks using techniques developed by D. Pollard and P. Segall.

Results

1. The accelerograms recorded in the gold mine provided the means of extending studies of seismic source parameters, peak velocities, and peak accelerations to considerably lower magnitudes. From the processed accelerograms source parameters were determined for four events, the smallest having a local magnitude, M_L, of -0.76, a source radius of 8 m, a seismic moment M_o of 4.5×10^{16} dyne-cm, and a stress drop of 25 bars. The stress drops for the other three events were in the range of 20 to 40 bars which tends to confirm the results of a previous study of source parameters of tremors in the range $0 < M_L \leq 3$ that the stress drops are between 5 and 50 bars. Thus, for the mine tremors, stress drops do not show any systematic variation over a range of 4 M_L units or about 5 orders of magnitude in M_o; this strengthens the conclusion that in terms of seismic source parameters there is no apparent difference between mine tremors and earthquakes.

Peak ground velocity ν appears to be very closely related to M_L or M_o. For the 12 mine tremors for which the accelerograms were processed to obtain ν a plot of log $(R\nu)$ as a function of M_L defined quite a precise line, where R is hypocentral distance in cm. The regression line through these data, extending over the range $-0.76 \leq M_L \leq 1.45$ turned out to be $\log R\nu = 3.93 + 0.54 M_L$. Interestingly, when this relation was extrapolated to $M_L = 5.0$ it was found to provide an excellent fit to the peak velocities of the Oroville, California aftershocks.

Observationally both $R\nu$ and the dynamic shear-stress difference $\tilde{\sigma}$, defined by Hanks and Johnsons as $\tilde{\sigma} = \rho R\underline{a}$ where ρ is density and $\underline{a}$ is peak acceleration, vary with M_o as $M_o^{1/3}$. The peak accelerations, however, are also influenced by the band width of the recording system roughly according to 2 fw, where fw is the upper frequency of the recording system. Accordingly, the a values for the mine tremors are considerably higher for an event of given M_o than for California earthquakes by approximately the ratio of the respective recording band widths of about 400 and 25 Hz.

2. The close observation and analysis of a mine-induced fault zone, which was correlated with a seismic event of $M_L = 2.1$, indicated that the rather complex fracture pattern was largely established before the main shock. It appears that the individual fractures comprising the overall fracture zone formed as a sequence of smaller shocks with relatively small displacements on each segment. This process established an instability which finally gave rise to the shock of magnitude 2.1 and typical shear displacements of about 6 cm.

Although the fracture pattern is complex, it consists of basically simple sigmoidal-shaped segments nested together in an en-echelon pattern. The basic pattern is repeated on many scales but the geometry seems to be scale-invariant. The en-echelon segments have typical ratios of overlap-to-offset of 4 with individual ratios varying from about 1 to 7.

Laboratory studies of the development of shear fracture in Witwatersrand quartzite indicate the throughgoing crack, which later fails in shear, is established before the peak in the stress-strain curve and thus is a stable phenomenon. The available evidence suggests that this is the case for the mine-induced shear zones as well.

Reports

McGarr, A., Pollard, D. D., Gay, N. C., and Ortlepp, W. D., 1979, Observations and analysis of structures in exhumed mine-induced faults: Proceedings of Conference VIII, Analysis of Actual Fault Zones in Bedrock, 1-5 April 1979, U. S. Geological Survey Open-File Report 79-1239, p. 101-120.

Retrieval of Earthquake Source Mechanisms Using Southern California Seismic Networks

14-08-0001-17749

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Investigations

1. Produce software designed to retrieve the seismic moment tensor from local digital recordings of earthquakes.

2. Analyses of the November, 1978, Oaxaca earthquake.

3. Trial-and-error modeling of near field data using complete synthetic seismograms computed using the Wavenumber Integration and Discrete Wavenumber/ Finite Element methods.

4. Investigate the role of source depth and local structure in the inverse problem of inferring the source mechanism directly from seismic recordings.

Results

1. Software have been developed to comptue the inverse problem in the time domain. Future investigations will involve testing of the technique in the frequency domain where the lower frequency and more stable portions of the seismograms can be readily treated.

2. The methods has been applied to the Oaxaca, Mexico earthquake of November, 1978. Further trial-and-error fitting of data to synthetic seismograms has allowed us to conclude: 1) The moment lies between 2.4 and 5×10^{27} dyne-cm; 2) The event is shallow, less than 25 km deep; 3) The slip vector corresponds to the well-known relative motion vector between the Cocos and North American plates; 4) The dip is small, less than 15°; 5) The stress drops associated with the high corner frequency of the source ($\sim$ 0.25 Hz) may approach a kilobar.

3. In order to stabilize the inverse problem it has been necessary to normalize all data to the same peak-to-peak displacement and to heavily weight the initial part of the seismogram.

4. Experiments with different velocity-depth models in the Imperial Valley clearly show substantial differences in the synthetic seismograms in all parts of the wavetrain for a very shallow cource in the sediments. The differences become less apparent as the source depth increases.

5. The effect of varying source depth, a non-linear constraint on the Inverse Problem, can be adequately accounted for through cataloging synthetic seismograms for several possible depths and allowing human intervention in the problem to decide which is most adequate.

6. Trial-and-error fitting of complete synthetic seismograms which include all near field terms, body and surface waves and leaky modes has been encouraging. In particular, a synthetic fit to a station from the 1977 Brawley swarm yielded a source moment corresponding to an M_L of 2.1 while the southern California network reported 2.2.

7. Two papers have been written, to date, sponsored by this contract and a third is in the final states of preparation. A paper was delivered at the spring SSA outlining the results of the work on the Oaxaca earthquake.

Reports

Ward, S., 1979. Body wave calculations using moment tensor sources in spherically symmetric, inhomogeneous media, Geophys. J. Roy Astr. Soc., in press.

Ward, S., 1979. A technique for the recovery of the seismic moment tensor applied to the Oaxaca, Mexico earthquake of November, 1978, Bull. Seism. Soc. Am., submitted.

Reichle, M., J. A. Orcutt, A. Reyes, K. Priestley and J. N. Brune, 1978. The 1978 Oaxaca earthquake and the 1973 Colima earthquake: Seismic moment, surface waves and body waves, Earthquake Notes, 49, 47.

W.A.

Seismicity and Tectonics

9920-01206

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Investigations

1. Peru Seismicity and Tectonics. Determine focal mechanisms of key earthquakes and integrate with results from previous studies made under this project, on relocated seismicity of Peru and on the 1974 Peru earthquake series.

2. Mantle Structure Beneath the Rio Grande Rift. Use a 3-D, seismic ray tracing algorithm to invert a set of teleseismic P-wave delay data, with the objective of determining the maximum depth and degree of velocity anomaly in the upper mantle beneath the Rio Grande Rift.

3. February 28, 1979 St. Elias (SE Alaska) Earthquake. Investigate main shock source properties.

Results

1. Peru Seismicity and Tectonics. The aftershock sequences of the great Peru earthquakes of 1966 (M_S=7 3/4-8), 1970 (M_s=7.8), and 1974 (M_s=7.8) each occurred in two or more clusters. The aftershock clusters spatially removed from the 1970 and 1974 main shocks are characterized by focal mechanisms that are dramatically different from the corresponding main shock focal mechanisms. One explanation of this disparity is that the events in the subsidiary clusters were triggered by the respective main shocks rather than representing a complex form of main shock rupture.

2. Mantle Structure Beneath the Rio Grande Rift. The attempt at inversion of the delay data is nearing completion. The inversion process has been severely handicapped by computer storage limitations. The necessary wide mesh spacing leads to a severe smoothing of much information contained in the P-wave delay data set. Only a gross model emerges: the central Rio Grande Rift has a P-wave velocity 4-6% lower than that of the adjoining Great Plains province, down to a depth of about 200 km $\pm$ 15 km.

3. February 28, 1979 St. Elias (SE Alaska) Earthquake. Based on 34 well-distributed observations, this earthquake has a size corresponding to M_S=7.2. Subroutines are being developed to analyze mantle waves for determination of seismic moment.

Reports

Dewey, J. W. and Spence, W., 1979, Seismic gaps and source zones of recent large earthquakes in coastal Peru, Pure Appl. Geophys. (in press).

Spence, W., 1979, Comments on the 24 May 1979 meeting on earthquake hazards in Peru, Memorandum to Bob Engdahl, Jerry Eaton, and others (August 1), 26 p.

W.B.

DIGITAL NETWORK OPERATIONS

9920-02398

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Investigations

The Global Network Operations continued to provide technical and operational support to the SRO/ASRO/HGLP observatories, which includes operating supplies, replacement parts, repair service, redesign of equipment, training and on-site maintenance, recalibration and installation. Maintenance is performed at locations as required but also each station is scheduled a visit by a technician every few months for preventive maintenance and training purposes.

The SRO installation at Bangui, Central African Republic, was completed in June.

The SRO systems at Albuquerque, Ankara, Chiang Mai, Bogota, Grafenberg, Narrogin, Shillong, Taipei, and ASRO systems at Kabul and Matsushiro were maintained and recalibrated. The borehole sensor at Taipei was replaced due to noisy output. The Mashhad SRO system has been down since November 1978 but, due to political problems, technicians have been unable to visit the station.

The DWWSSN modified prototype amplifier assembly was received from Teledyne-Geotech, tested and accepted. Also four production models of the amplifiers have been received and four complete DWWSSN system are now under test.

During this period, Howell Butler met with host organizations at Bergen, Jeddah, Karachi, Hong Kong, Taipei, Adelaide, Hobart, Canberra, Sydney, Apia and Honolulu to discuss the Blobal Network. Operations and the shipping of the data, supplies and parts to/from host agencies.

Results

The network provides improved geographical coverage with highly sensitive short and long period seismic sensors with analog and digital magnetic tape recordings.

W.B.

USGS AND COOPERATIVE OBSERVATORIES

9920-01261

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Investigations

Field activities consist of occasional visits to the seismic stations for the purpose of maintenance, calibration, or installation of new instrumentation. Stations are provided with advice on operation, maintenance, and calibration. Also all stations are provided with spare parts, operational supplies, and replacement modules.

Results

These observatories contribute essential data to the NEIS both routinely and on a rapid basis when required. The locations were selected to fill gaps in stations locations and to provide better coverage for local events. All data are available for other seismologists when required.

W.B.

WORLD-WIDE STANDARDIZED SEISMOGRAPH NETWORK (WWSSN)

9920-01201

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Investigations

The Global Network Operations continued to provide technical and operational support to the WWSSN observatories as funding and staffing permitted.

During this period, 205 WWSSN modules were repaired and 189 separate shipments were made to support the network. Fifty-eight stations were supplied with annual shipments of photographic materials and emergency shipments were made to ten stations.

WWSSN observatories at Manila (MAN), Lormes (LOR), Seoul (SEO), Poona (POO) Kodaikanal (KOD), Shillong (SHL), New Dehli (NDI), Quetta (QUE), Helwan (HLW) and Nilore (NIL) were completely serviced and recalibrated and cabling and marginal components were replaced or repaired as needed. The Manila, Lormes, Seoul and Nilore stations were restored to operational status after a long period of down times. The Seoul equipment was reinstalled in a new vault and observatory. At Nilore, the recording was moved from the basement of the observatory up to the first floor. A total of 52 WWSSN stations have been maintained and recalibrated in the last two years.

Howell Butler visited the Hong Kong, Kingsberg, Adelaide, Tasmania, Riverview, Afiamalu and Kipapa WWSSN stations to discuss the Global Network programs and the shipping of parts and data to/from the host agencies.

Results

A continual flow of high quality seismic data from the network of 115 observatories for use by the seismological community.

U. S. Seismic Network

9920-01899

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Investigations and Results

As an operational program, the U.S. Seismic Network operated normally throughout the report period. Data was recorded continuiously in real time at the NEIS main office in Golden, Colorado. At the present time, 64 channels of SPZ data are being recorded at Golden on Develocorder film. A representative number of SPZ channels are also recorded on Helicorders to give NEIS real time monitoring capability of the more active seismic areas of the U.S. In addition, six channels of LPZ data are recorded in real time on multiple pens Helicorders.

Last spring a data exchange agreement with ATWC, the Alaska Tsunami Warning Center, Palmer, Alaska was implemented. Nine channels of 20 sample per second SPZ data are transmitted continuously in both directions via satellite between ATWC and NEIS. A 2400 BPS data stream on an existing BLM circuit is being used to transmit the data, keeping costs very low.

Data from the U.S. Seismic Network is interpreted by record analysts and the seismic readings are entered into the NEIS data base. The data is also used by NEIS standby personnel to monitor seismic activity in the U.S. and worldwide on a real time basis. At the present time, all earthquakes large enough to be recorded on several stations are worked up using the "Quick Quake" program to obtain a provisional solution as rapidly as possible. Finally, the data is used in such NEIS publications as the "Preliminary Determination of Epicenters" and the "Earthquake Data Report".

Development work is continuing on an event detector to monitor the U.S. Seismic Network in real time. Current plans are to use several PDP 11/03 micro computers to monitor the data and pass events on to a larger machine for further processing.

The goals of the U.S. Seismic Network are to upgrade the quantity and quality of the data received to make possible more rapid and accurate location of U.S. earthquakes and significant earthquakes worldwide.

SYSTEMS ENGINEERING

9920-01262

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Investigations

1. Design, develop, and test microprocessor based seismic instrumentation.

2. Design, develop, procure, and test special electronic systems required by the seismic observatories.

3. Design, implementation, and testing of microprocessor/computer software programs for seismic instrumentation and seismic data recording systems.

Results

1. A special modification to the WWSSN Digital Recording System (DRS) to isolate the DRS from the main WWSSN console in the event of power failure in the DRS has been designed, built and tested. This modification will be built into all production DRS Systems.

2. Preliminary versions of the DRS Short Period (SP) event detector program and the Intermediate Period (IP) event detector program have been completed and will be operational for the first DRS Systems which will be installed during December/January 1979.

3. The design for the Digital Telemetry System is complete. Assembly and checkout will begin in mid October 1979. The initial system will be a 2400 baud unit and second unit with increased channel capacity will be a 4800 baud unit.

4. The design for the fault monitor system is complete and assembly has started. All mechanical components have been tested and only the microprocessor based recording system needs assembly and testing. This project is a joint effort between Branch of Global Seismicity, ASL Engineering, and the Branch of Earthquake Tectonics and Risk (Bob Bucknam).

W.B.

TSUNAMI NETWORK SUPPORT

9920-01263

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Investigations

1. Design, develop, and test microprocessor based TSUNAMI related seismic and tide system.

2. Design, develop, and test GOES SATELLITE related Tsunami data transmission techniques and instrumentation.

Results

1. Preliminary plans for the installation of four TT-3 Tide Systems in the South American area have been completed. This project is a joint effort between the USGS and NOAA/NWS. These four Tide Systems will operate over the GOES SATELLITE Network. Installation of these stations will improve the tide reading response time for TSUNAMI detection for seismic events near the western coastal areas of South America. The exact location for these stations have not been announced by NOAA/NWS. Installation should be completed by July-August 1980.

2. Plans for the testing of a TS-4 Seismic System at Guam during October 1979 have been completed. Test results will determine if a future TS-4 Seismic System will be permanently installed at Guam.

W.B.

DIGITAL NETWORK DATA PROCESSING

9920-02217

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Investigations and Results

1. The primary effort in this project is the processing of digital seismic data recorded on magnetic tapes from the Global Digital Seismic Network. During the past six months, 222 digital tapes were edited, checked for quality, corrected when feasible, copied and distributed to data users.

2. During the past two years, the data from all SRO and ASRO stations has been transmitted via the ARPA Computer Networks into a mass storage system called the data computer located in Cambridge, Massachusetts. As of September 30, 1979, this program has been terminated. Data transmission is complete through December 31, 1978, for all stations in the digital network.

3. The project to construct network-day tapes consisting of 24 hours of seismic data from each station of the Global Network is progressing more slowly than anticipated. All of the computer hardware equipment necessary to assemble the network-day tapes has been installed and is operating. This consists of two PDP 11/34 Processors, two large disc pac memory systems, several tape drives and various other terminals, printers, and plotters. The 11/34 Processors are using the UNIX Operating System, Version 6, and which was developed by the Western Electric Corporation. It has been necessary to learn this new operating system, correct a number of problems or bugs in the system and develop new drivers for the various peripherals. All of this work has been completed and the software programs for the network-day tapes are now under development. A Contract has been let to the Digital Graphics Corporation of Rockville, Maryland, to supply computer operators for the assembly of the data tapes. This program is scheduled to be operational in January, 1980.

Reports

Murdock, James N., Ross, Jerry D., and Hoffman, John P., 1978, Variations of the Short-Period Microseisms at the SRO and ASRO Stations: (Abstract), Earthquake Notes, Vol. 49, No. 4, p. 92.

Murdock, James N., Ross, Jerry D., and Hoffman, John P., 1978, Stability of the Amplitudes of the Long-Period Calibrations of the Seismic Research Observatories: (Abstract), Earthquake Notes, Vol. 49, No. 4, p. 92.

ALBUQUERQUE OBSERVATORY

9920-01260

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Investigations

A High Gain Long Period station has been installed (in facilities provided by New Mexico Tech) in Socorro, New Mexico. The System Gain at 30 seconds has been set at near 50K on the visible monitor. The data will be telemetered to the Albuquerque Seismic Laboratory and recorded there on a digital tape machine. The station is the second of a three station network planned in central New Mexico.

Results

Progress is being made on the new observatory facility. Equipment racks have been installed, a sub-floor cooling system for the electronics is operational, and the plumbing for four develocorders has been installed. Work is progressing on the standby power system and telemetry systems at the present time.

Reports

None

Seismic Observatories

9920-01193

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Investigations

Recorded and provisionally interpreted seismological and geomagnetic data at observatories operated at Newport, Washington; Cayey, Puerto Rico; Adak, Alaska; and Guam. At Newport, Washington and Guam, 24-hour standby duty was maintained to provide input to the Tsunami Warning Service operated at Honolulu Observatory by NOAA.

Effective at the end of this report period, Newport Observatory will assume night time responsibility for the Early Earthquake Reporting System. This means that during off duty hours information on felt and damaging earthquakes in the United States and world-wide events with magnitudes greater than approximately 6.5 will be located and reported from Newport rather than from the NEIS in Golden, Colorado.

Results

Continued to provide data on an immediate basis to the National Earthquake Information Service and the Tsunami Warning Service. Supported the Puerto Rico Project of the Branch of Earthquake Tectonics and Risk. Provided geomagnetic data to the Branch of Electromagnetism and Geomagnetism. Responded to requests from the public, interested scientists, state and federal agencies regarding geophysical data and phenomena.

Worldwide Earthquake Research Database

9930-02104

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Investigations

The main goal of this project is to provide up-to-date information which will facilitate research on earthquakes. Three major topics are now under investigation:

1. Establish a seismograph library of significant earthquakes (especially those before 1963).
2. Organize and maintain a bibliographic data base and retrieval system on current earthquake literature, and
3. Compile an accurate catalog of worldwide earthquakes.

Results

Seismogram Library. Under contract from this project, the National Geophysical and Solar-Terrestrial Data Center, NOAA, has built a portable photocopying system for filming historical seismograms. Seismograms from key U.S. stations are now being filmed. Please see Meyers and Lee (1979) for details.

Bibliographic Database and Retrieval System. The Current Earthquake Literature (CEL) database has been maintained and kept up to date. Bimonthly indexes are being distributed on schedule.

Seismic Data Processing System. A modern seismic data processing system for visual seismograms was built using mostly surplus components. It is capable of processing seismograms in any currently existing format at a rate that is a few times faster than previous techniques.

Reports

Meyers, H., and Lee, W. H. K., 1979, Filming historical seismogram project: First progress report (in press).

Gunn, M., and others. Index to Current Earthquake Literature (bimonthly issues).

W.C.

Seismic Review & Data Services

9920-01204

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Investigations and Results

The quality control and technical review of 115,000 seismograms (629 station months) generated by the World-Wide Standardized Seismograph Network (WWSSN) was carried out.

The annual Station Performance Reports which detail instrumental accuracies, timing precision, noise patterns and intensities, recording quality, records reviewed, and any unusual operational problems noted, were sent to half of the network stations (55). The reports for the other half of the network are in preparation. Operational standards and seismogram quality of high levels are still being maintained. Timing accuracies are still on the average under 50 milliseconds daily error. Polarity problems crop up from time to time at a few stations such as Rabaul, New Guinea (RAB), and Seoul, Korea (SEO). At Georgetown (GEO), the long period vertical polarity problem still persists, and at Stuttgart, W. Germany (STU) the short period horizontals still show calibration reversals.

No seismograms have been received from the Iranian WWSSN and ASRO stations over this period (TAB, SHI, MHI, SHIO).

The computerized monthly update report covering WWSSN records received, date received, station changes, backlogs, instrumental magnifications has been expanded to include the Seismic Research Observatory (SRO) data and the Abbreviated Seismic Research Observatory (ASRO) data. These reports are supplied to USGS and NOAA officials and scientists routinely.

Completion of the modifications to the two inhouse microfilm reader-printers (dry-process paper reproduction system, and new optical systems to handle 70mm chip, 35mm roll, and fiche formats) were completed. Filing systems to accommodate these formats as a function of cost/space considerations are being examined. Completed library will house film formats of the WWSSN, ASRO, SRO, and Historical Files, will be available to resident and visiting scientists.

United States Earthquakes

9920-01222

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Investigations

1. Forty-two earthquakes in 15 states were canvassed by a mail questionnaire for felt and damage data. The questionnaires plus additional data from collaborators, newspapers, and personal contacts have been evaluated for intensity value. A field investigation of the February 28, 1979, St. Elias, Alaska earthquake was conducted in early April.

2. The United States earthquakes for the period April 1, 1979-September 31, 1979 have been located and the hypocenters, magnitudes, and maximum intensities have been published in the Preliminary Determination of Epicenters.

3. The maps of the seismicity of the states of Ohio, Indiana, Illinois, Missouri, Arkansas, Kentucky, and Tennessee have been completed and are being printed. These maps are at a scale of 1:1,000,000.

Results

The maximum intensity assigned to an earthquake from April 1, 1979 to October 1, 1979 was VII for the August 6, 1979 event near Gilroy,California. It was located at 37.101^{o}N, 121.503^{o}W, orgin time 17 05 22.7 UTC, depth 6 km, magnitude 5.3 mb (USGS), 5.6 MS (USGS), 5.9 ML (BRK). The press reported $250,000 damage in Hollister and $100,000 in Gilroy. Intensity VII effects occurred at both Gilroy and Hollister. Some of the effects at Hollister were merchandise in grocery and liquor stores thrown from shelves and broken, light fixtures fallen, a ceiling collapsed, cracks in exterior walls of buildings, bricks fallen from buildings, windows broken, power lines swung together and shorted out until burned into, heavy safety deposit boxes in a bank moved several inches, four buildings declared structurally unsafe. Gilroy sustained the same type of damage as Hollister with five buildings sustaining significant structural damage.

Reports

Stover, C. W., Reagor, B. G., and Algermissen, S. T., 1979, Seismicity map of the state of Georgia: Miscellaneous Field Studies Map 1060.

Stover, C. W., Reagor, B. G., and Algermissen, S. T., 1979, Seismicity map of the state of Louisiana: Miscellaneous Field Studies Map 1801

Person, W. J., 1979, Earthquakes, September-October 1978: Earthquake Information Bulletin, v. 11, no. 2, p. 71-73.

Person, W. J., 1979, Earthquakes, November-December 1978: Earthquake Information Bulletin, v. 11, no. 3, p. 110-112.

Person, W. J., 1979, Earthquakes, January-February 1979: Earthquake Information Bulletin, v. 11, no. 4, p. 143-147.

Person, W. J., 1979, Seismological Notes, July-August 1977: Seismological Society of America Bulletin, v. 69, no. 2, p. 651-653.

Person, W. J., 1979, Seismological Notes, September-October 1977: Seismological Society of America Bulletin, v. 69, no. 3, p. 925-927.

Person, W. J., 1979, Seismological Notes, November-December 1977: Seismological Society of America, v. 69, no. 4, p. 1301-1304.

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