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Southern California Earthquake Center Annual Meeting

October 29-31, 1991

NSF/USGS Site Review
SCEC Advisory Council Meeting

November 1, 1991

University Hilton Hotel
Los Angeles, California

Telephone (213) 740-5843 FAX (213) 740-0011

Table of Contents

Note: This report is preliminary and not intended to be complete. Activities with regard to education/outreach, SCEPP, and SCEC infrastructure has not been included.

Academic Co-Investigators (1991)

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University of Southern California: (Coordinating Institution)	Keiiti Aki Thomas Henyey Peter Leary Geoffrey Martin	William Petak Charles Sammis Ta-liang Teng
California Institute of Technology:	Robert Clayton Egill Hauksson Donald Helmberger	Kenneth Hudnut Hiroo Kanamori Kerry Sieh
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University of California, Los Angeles:	Paul Davis David Jackson	Yan Kagan Leon Knopoff
University of California, San Diego:	Duncan Agnew Yehuda Bock	Bernard Minster John Orcutt
University of California, Santa Barbara:	Ralph Archuleta Ruth Harris Edward Keller Stephen Miller	Craig Nicholson Stephen Richard Bruce Shaw Sandra Seale
University of California, Santa Cruz:	Thorne Lay Karen McNally	Steven Ward

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University of California, Riverside:	Stephen Park	
University of Nevada, Reno:	John Anderson	Steven Wesnousky
San Diego State University:	Steven Day	Thomas Rockwell
Harvard University:	James Rice	
Stanford University:	Allin Cornell	
Massachusetts Institute of Technology:	Bradford Hager	
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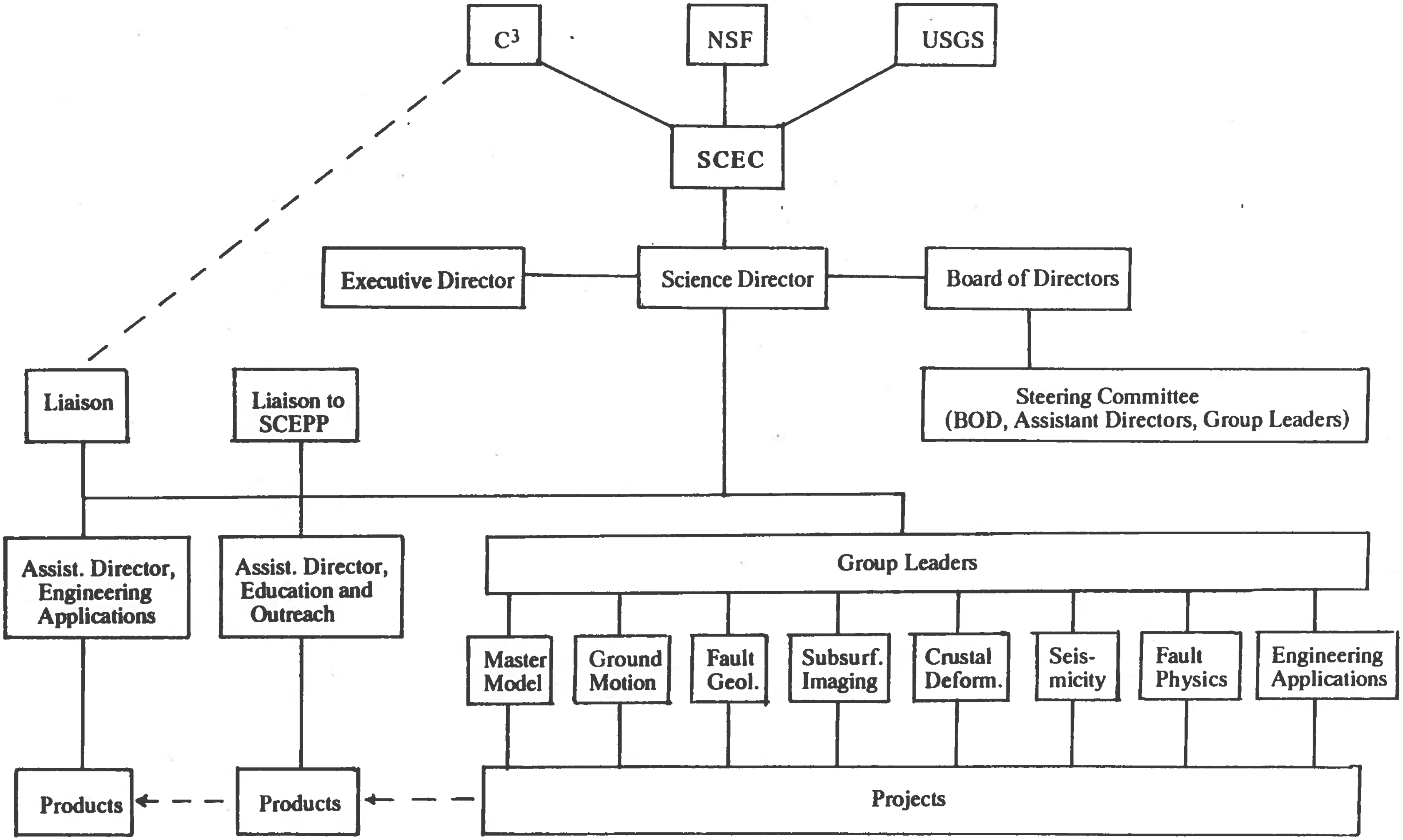
SOUTHERN CALIFORNIA EARTHQUAKE CENTER (SCEC) ORGANIZATION



SCEC ANNUAL MEETING AGENDA

TUESDAY, OCTOBER 29

Morning session: 9:00 a.m. to noon

SCEC Administrative Report	Tom Henyey
SCEC Overview	Kei Aki
SCEC/USGS Pasadena Office	Tom Heaton
NSF Comments	Jim Hays
USGS Comments	Elaine Padovani
Education and Outreach/SCEPP	Karen McNally

Coffee Break (Demonstration of probability maps by Luci Jones)

Working Group Reports of Year 1 Progress (discussion follows each group report):

Group A (Master Model)	Kei Aki/Luci Jones/ Steve Park
Group B (Strong Motion)	Steve Day
Group C (Fault Zone Geology)	Kerry Sieh

Lunch provided at hotel (noon to 1:00 p.m.).

Afternoon session: 1:00 p.m. to 5:30 p.m.

Group D (Subsurface Imaging)	Rob Clayton
Group E (Geodesy)	Dave Jackson
Group F (Regional Seismicity)	Egill Hauksson
Group G (Earthquake Physics)	Leon Knopoff

Coffee break.

Group H (Engineering Applications)	Geoff Martin
Terrascope	Hiroo Kanamori
CUBE	Egill Hauksson
Data Center/Catalog Update	Rob Clayton
Refteks	Aaron Martin
GPS	Dave Jackson
Pinon Flat	Bernard Minster

WEDNESDAY, OCTOBER 30

Morning Session: 9:00 a.m to noon.

Individual Working Group Meetings:

Group D	Rob Clayton
Group E	Dave Jackson

Lunch provided at hotel (11:30 a.m. to 12:30 p.m.).

Afternoon session: 12:30 p.m. to 3:30 p.m.

Group A	Kei Aki
Group F	Egill Hauksson
Group C	Kerry Sieh

Coffee break.

3:30 p.m. to 6:30 p.m.

Group B	Ralph Archuleta
Group G	Leon Knopoff

7:30 p.m.

Evening Session on Education and Outreach: Discussion led by Karen McNally and Tom Henyey.

THURSDAY, OCTOBER 31

Morning session: 9:00 a.m. to 12:30 p.m.

Reports on future plans from working group leaders:

Group E	Dave Jackson
Group B	Ralph Archuleta
Group C	Kerry Sieh
Group D	Rob Clayton

Coffee break.

Group F	Egill Hauksson
Group G	Leon Knopoff
Group A	Kei Aki

End of SCEC Meeting.

Lunch Meeting (**12:30 to 2:00**) SCEC/IRIS Issues Forum: Tim Ahern and Tom Henyey will lead discussion.

Issues:
- PASSCAL Instruments
- Post-Earthquake Response
- Data Management

Afternoon session: 2:00 p.m. to 5:00 p.m.

SCEC Steering Committee* meets to summarize workshop, and prepare report to Advisory Council and preliminary plan for NSF.

*SCEC Board of Directors, plus Kerry Sieh, Egill Hauksson, Leon Knopoff, and Geoff Martin.

Get-acquainted meeting of SCEC Advisory Council.

FRIDAY, NOVEMBER 1

Morning Session: 8:30 a.m. to noon

SCEC Steering Committee meeting with SCEC Advisory Council and NSF/USGS Site-Review Team. Progress report and plans for year 2. Discussion should consider SCEC Evaluation Criteria.

Noon to 1:00 p.m.

Lunch for SCEC Advisory Council and NSF/USGS Site-Review team.

Afternoon Session: 1:00 p.m. to 2:30 p.m.

Executive Session: SCEC Advisory Council and SCEC Steering Committee.

2:30 p.m. to 4:00 p.m.

Executive Session: NSF/USGS Site-Review Team and SCEC Steering Committee.

SCEC OVERVIEW, 1991

by Keiiti Aki

Tom and I share the responsibility of the director's office at SCEC. Tom has been doing a superb job in his part, managing the complex operation of an enormous consortium of universities, meeting deadlines for the demanding NSF center program, exploring new funding sources, and developing cooperative programs with various government agencies concerned with earthquake hazards in southern California.

My part is called the "science director". I am responsible for achieving the goal of the center, which is to integrate research findings from the various disciplines in earthquake related sciences in order to develop a probabilistic seismic hazard model, what we call the "master model", for southern California. We propose to construct the master model through various meetings and workshops where it will be debated, improved, updated, and developed into forms applicable to earthquake hazard mitigation.

The present 3-day meeting is our first attempt for constructing this model by joining all the SCEC members.

In the past eight months since the center was born, we have already had many meetings and workshops, including meetings of individual working groups, regular monthly meetings of all members, and workshops designed for integration of specific disciplines attended also by invited outside experts. One such workshop was held last June at Santa Barbara, on the physics of earthquake source and was attended by physicists, rock mechanicists and seismologists. Another one was held at Pasadena, about a week ago to explore the future working relationship between geotechnical engineers and seismologists. I attended most of these meetings and began to see the efforts for integration of research and interaction of different disciplines toward our goal. I realized, however, some of the elements of the master model take longer times than others before such interaction and integration can take place. This is true with most of the observational elements, including GPS, fault zone geology and imaging. Thus, my overview of the first 8 months of SCEC activities tend to emphasize theoretical and computational elements of the master model.

This morning, I would like to tell you what I found through these meetings and my personal view of the direction we are moving. I shall first describe some of the important results directly relevant to the construction of the master model, and then those relevant to the application of the master model.

I believe that we now have a solid physical foundation upon which we can start constructing our master model. This foundation is based on the conclusion presented at several SCEC meetings by Jim Rice. According to Rice, a homogeneous fault plane which obeys the rate- and state- dependent friction law with parameters varying with depth as functions of temperature and normal stress will produce a simple cyclic occurrence of earthquakes of same characteristics, and will never produce the observed spatio-temporal complexity of fault slip such as the Gutenberg-Richter power law magnitude-frequency relation. He suggested that the reasons why some people obtain power law distribution for a uniform fault may be due to inadequate discretization of the continuum, or to the absence of the slip-weakening friction law or else to computational difficulties with oversized problems.

Since Rice's conclusion is fundamental to the construction of our master model, I would like to propose to call it Rice's law. An important implication of Rice's law is that heterogeneities or nonuniformities in material strength or fault plane geometry with a wide range of scale lengths are essential ingredients of fault physics. I observe that this is now a consensus of the working group G on fault physics under the leadership of Leon Knopoff, and I feel that this consensus was made possible by the center-mode research in which a broad-minded interaction has taken place among physicists, geophysicists and geologists. These fundamental propositions on fault physics are directly relevant to the application of our master model in the form of probabilities of earthquake occurrence. Two basic parameters of the earthquake recurrence statistics are the mean recurrence time (T) and its spread (σ). The 1988 working group has adopted the log normal distribution proposed by Nishenko and Buland (1987) who found that $\sigma=0.21$ from global data on recurrence intervals.

Seismicity simulation can give us some insight into how these parameters should depend on the physical and geological conditions of a particular fault segment. For example, Steven Ward estimated the value of σ using a model of segmented faults for the earthquakes in the Middle America trench, and found that σ is about 0.7, much larger than the Nishenko-Buland value. He found also that, in general, the stronger segment shows smaller σ and tends to generate more characteristic earthquakes. This is intuitively acceptable, because weaker segments would be affected more easily by the interactions of other segments than stronger ones. In fact, Savage's chi-square testing of the Nishenko-Buland hypothesis, revealed that, although the statistical significance was marginal, the recurrence intervals were more constant for two Chilean segments, and more variable for the Parkfield segment than the hypothesis predicted. These differences may be attributed to the differences in the physical and geometrical characteristics of the respective fault segments.

Ideally, we would like to develop a master model which can account for all the interactions between segments of a given fault zone, and between segments of different fault zones such as the main San Andreas fault, subparallel strike slip faults, and thrust faults in southern California, as well as coupling of seismic fault slips with aseismic slips and deformation in the ductile part of the lithosphere.

These interactions require a full 3-D model for their understanding. On the other hand, the construction of a realistic 3-D master model for southern California is probably impractical at this stage. A viable approach may require two parallel complementary research directions. In one of them, we shall study each of the interaction process separately using a full-3-D model but under idealized geological and geophysical conditions. In the other, we shall construct a 2-D master model of earthquakes for the realistic conditions of southern California. The 3-D studies will be used to check the validity of approximations of 2-D studies locally. The global aspects of the problem will be studied using the 2-D model. We shall need to assign parameters of these models through geological and geophysical characterization of earthquake faults. Here, more intensive integration of efforts of different working groups is needed. We need more productive interaction among groups working on fault geology, seismic imaging, fault physics, seismicity and crustal deformation. How we accomplish this integration of efforts in the immediate future is the most crucial issue of this meeting. The success or failure of our center depends on how we can integrate these various disciplines to obtain adequate estimates of parameters to be used in our seismicity model for Southern California.

How do we promote necessary interactions among different working groups? For example, during the Santa Barbara workshop Jim Byerlee proposed the existence of strong pore-pressure gradient in the fault zone in the direction perpendicular to the fault plane. Such a zone shall affect the characteristics of trapped modes, head waves and other seismic signatures of the fault zone and should be an excellent target for the fault zone seismology group. Effective points of interaction among different groups may be brought out by asking questions to other groups.

Such a question which may serve as a focal point of interaction among different groups was asked by Dave Jackson at the recent UCLA meeting. His question is about the recent increase in the activity of moderate thrust earthquakes in the LA Basin, from the Whittier Narrows to the Sierra Madre with an apparent northward migration. He asks if this activity has anything to do with the San Andreas fault. Ken Hudnut has a model in which these thrust faults may be connected through aseismic slip across a detachment fault. Can we estimate any change in probability of earthquake occurrence on the San Andreas fault as a result of these moderate thrust earthquakes?

We need to ask questions like these to promote interactions among different working groups, and I encourage you attend as many working group meetings scheduled tomorrow as you can.

Let us now shift our attention closer to the application element of master model. As I mentioned earlier, our center sponsored a one-day workshop about a week ago at USC's Gamble House in Pasadena to explore the future working relationship between geotechnical engineers and seismologists. This Gamble House workshop was a natural growth of interaction between Liam Finn and myself who were asked to present the state-of-the-art papers for the recent International Conference on Seismic Zonation held at Stanford. I shall go into some details on this subject because of my personal involvement, as you'll hear details on other subjects from leaders of working groups later today. The Gamble House workshop was started with my presentation of recent seismological evidence supporting a pervasive non-linear site amplification at soil sites.

The evidence is a systematic difference in frequency dependent site effect between the weak (low strain) motion and the strong (high strain) motion. The data from the regional network in central and southern California revealed that, on the average, the weak motion amplification factor is greater at soil sites than rock sites at all frequencies at least up to 12 Hz. On the other hand, the accumulating data throughout the world indicates that the strong motion amplification factor is greater at soil site than rock sites only for frequencies lower than about 5 Hz, and the relation is reversed for higher frequencies on the average.

The second evidence is the results from the Loma Prieta earthquake. The weak motion amplification factor applied very well to the strong motion recorded at distances longer than about 50 km, but gave considerable overestimates for stations at soil sites within 50 km from the hypocenter.

These observed non-linear effects are consistent with the prediction by geotechnical engineers based on the laboratory results on the behavior of soil under a strong shaking.

My presentation was followed by heated discussions which lasted for the whole day. By the end of the day, however, when we went around the table asking what we should do in the future, I felt a consensus emerging from the participants, which may be summarized in the following three recommendations. (1). There is an urgent need for characterizing the geologic conditions under which the site effects are non-linear, linear or transitional. For this purpose, we need to reoccupy the seismograph sites where strong motion data already exist to collect weak-motion data. (2). We need dense 3-D arrays of high-quality seismographs in an area where strong shaking is anticipated, so that the type of research done by C. Y. Chang using the data from SMART-1 array in Taiwan, which also demonstrated the non-linear effect, can be repeated for other sites. (3). We need to broaden our views encompassing both geotechnical engineering and seismology in order to interface the one-dimensional non-linear approach of the former with the 2-D, 3-D linear approach of the latter including the source and propagation path effect. This is somewhat similar to the dual approach I recommended earlier for seismicity simulation.

The workshop was very refreshing to me because everyone spoke out what they really think, believe and want to do. One of the reasons for this free direct communication may be because nobody from the funding agency was there. The successful Gamble House workshop may offer another justification for the center mode of doing research.

I would now like to address the application of master model. In this aspect, I like to bring out one of important areas of urgent research needs identified in my state-of-the-art paper presented at the Stanford Conference on Seismic Zonation mentioned earlier. There is a need for improvement in the relation with the community of users of the earth science information. The user community is diverse, and the ground motion parameters required are also diverse. It is impractical to prepare common omni-purpose zoning maps meeting all of their needs. I envisioned the following procedure as the future seismic zoning.

Since any ground motion parameters can be extracted from the acceleration time series, we can compute the time series for a given source-receiver pair using the state-of-the-art method on the basis of our current knowledge on the earthquake source, propagation path and recording site condition. We then can extract the ground motion parameter requested by a customer, and attach the probability of the occurrence of the particular earthquake to this parameter. Repeating the same procedure for all relevant source-receiver pairs, we can synthesize the results into site-specific, or a map view of the parameter for a given exceedance probability in the usual manner of probabilistic seismic hazard analysis.

When I prepared the state of the art paper, I thought this was a futuristic dream. The GIS technology, however, apparently is ready to deal with such a task. In a recent meeting of SCEC subgroup on mapping chaired by Charlie Sammis, I was very much impressed by the unanimous enthusiasms of the subgroup members to proceed beyond a printed standard hazard map to the GIS technology based maps which can accommodate constantly updated information and be tailored to the specific need of a customer.

In summary, I am very much excited by the momentum being gained in both construction and application of the master model of southern California earthquakes. The progresses we are making appear to be very fundamental, and their impact on earthquake hazard mitigation research will be long lasting. What we need now is to proceed more vigorously with the integration of observational elements of the master model, and try to focus on the short-term goal without sacrificing the importance of the long-term goal of earthquake hazard mitigation in southern California.

Southern California Earthquake Center

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NSF/USGS SITE VISIT OF THE SCEC
November 1, 1991

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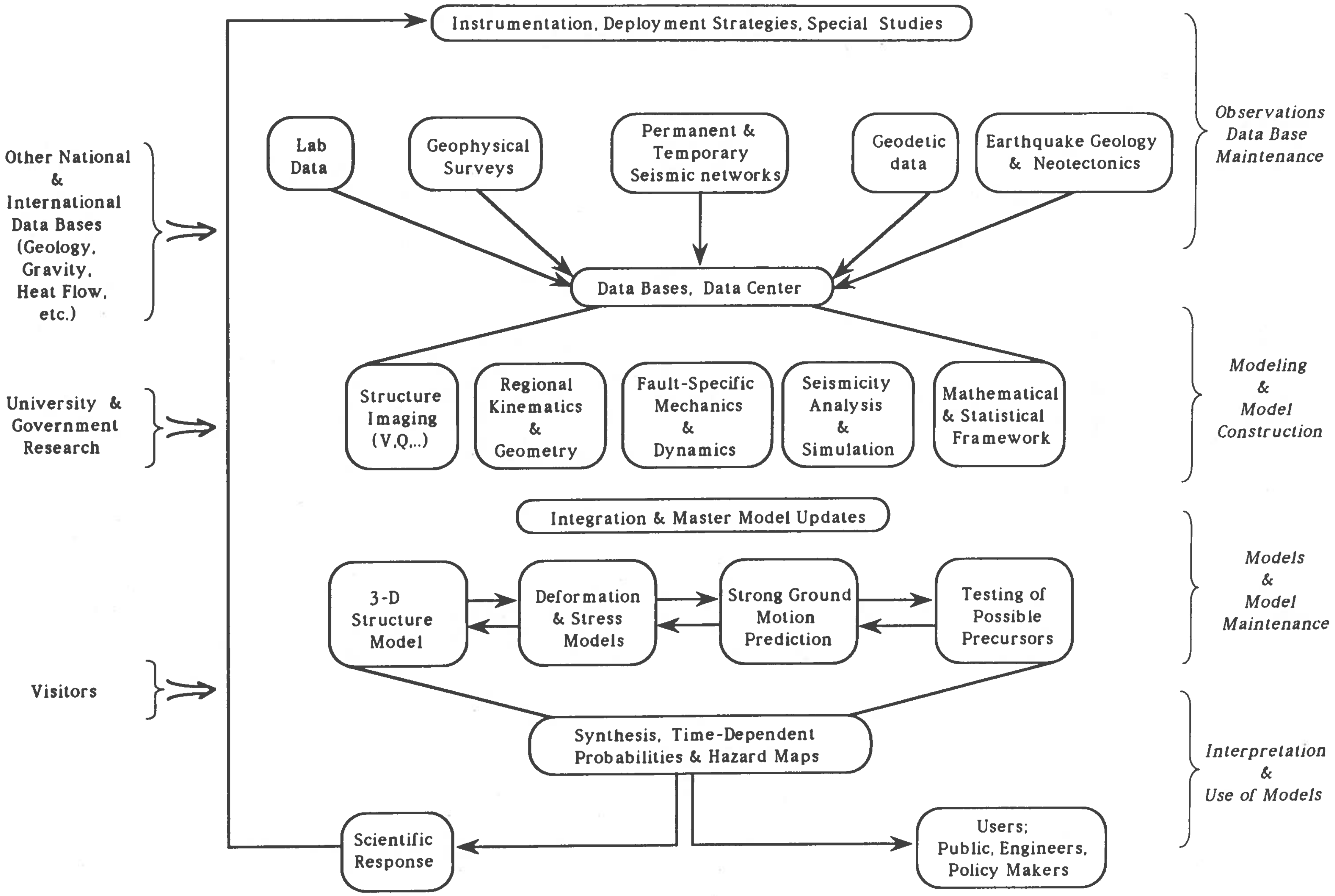
THE MASTER MODEL



SOUTHERN CALIFORNIA EARTHQUAKE CENTER (SCEC) EVALUATION CRITERIA

I. Goal of the Center

The Southern California Earthquake Center (SCEC) is composed of scientists from seven core institutions and a number of participating institutions, in partnership with the United States Geological Survey's Office of Earthquakes, Volcanoes, and Engineering (USGS). The goal of the Center is to integrate research findings from the various disciplines in earthquake-related science in order to develop a prototype probabilistic seismic hazard model (master model) for southern California. The master model will represent a distillation of Center thinking which is developed through various meetings and workshops, and updated on a regular basis as new research results become available. This distillation may be stated in terms of a consensus on some issues, while on other issues it may be represented in terms of two or more differing opinions.

II. Research and Research Performance

A. Research Directions and Objectives

Master Model Construction

The master model is a framework in which geologic, geodetic, geophysical, and seismological information pertinent to earthquakes will be integrated for the purpose of developing a prototype probabilistic seismic hazard analysis of southern California. SCEC will develop, refine and apply (i.e. transfer to the user community) the master model on one hand, and acquire and integrate the pertinent data for model improvement on the other. Its substance will be debated in regularly scheduled workshops, and developed into forms applicable to earthquake hazard mitigation in the public and private sectors.

Master Model Improvement and Maintenance

The requirements of the master model will guide data acquisition and interpretation through the processes of interaction and feedback. As such, the master model will be constantly improved and updated as new research results become available. To facilitate master model improvement and define its research directions and objectives, the Center has been configured into eight disciplinary working groups as follows:

- *A) Seismic Hazard Analysis and Master Model Construction*
- *B) Strong Ground Motion Prediction*
- *C) Fault Zone Geology*
- *D) Subsurface Seismic Imaging*
- *E) Crustal Deformation*
- *F) Regional Seismicity*
- *G) Physics of Earthquake Sources*
- *H) Engineering Applications*

The research results of working groups B to F will provide input to the master model, and when fully integrated by working group A, will be the best representation of the earthquake process. Group A will maintain the master model in its most current form. The master model will be maintained as a data base, a set of model parameters, and a set of products (principally digital maps) at the SCEC data center in Pasadena. Working group H will provide for engineering applications of the master model.

Master Model Output

The products derived from SCEC research will consist largely of maps and data bases related to probabilistic estimates of earthquake occurrence and strong ground motion. Estimates of strong ground motion depend on a knowledge of fault failure as well as propagation path and local site conditions, particularly since the population distribution in southern California is concentrated away from the main San Andreas fault.

The Center will undertake the hazard analysis in two steps. The first step, which will be completed in two years, will involve updating the geologic data on faults (mainly from trenching), and determining the propagation and site effects to construct maps of exceedance probabilities for strong ground motion parameters in southern California. The second step, which will be completed in five years, will involve adding to our hazard analysis the new geodetic data, particularly those data relevant to blind thrusts. In its product, the Center will combine all pertinent information on earthquake hazards using a Bayesian approach.

B. Measures of Research Performance

- *Publication*
  - What is the scientific and/or technical impact of research results in guiding other research and in improving probabilistic hazard analyses?
  - Are papers published in peer-reviewed scientific journals?
  - Is there timely dissemination of information regarding center workshops to the scientific community and publication of technical reports detailing various elements of the master model?
  - Are information circulars published from time to time, for example, after major earthquakes or to assist in classroom instruction?

- *Interaction*
  - Is the Center, through its working group structure and its focus on the master model, and through workshops, monthly meetings, special symposia, and joint publications effective in facilitating scientific interaction?
  - Does the Center facilitate interaction between the various earth science disciplines involved in earthquake studies and seismic hazard analysis?
  - Does the Center facilitate interactions between scientists at the participating institutions and the USGS?
  - Does the Center facilitate interactions between earth scientists and engineers?

- *Master Model Impact*
  - What is the impact of the master model on the earth sciences and on earthquake hazard reduction methodologies?
  - Do the scientific and earthquake hazard mitigation communities accept the master model as a useful way of both structuring scientific research programs on earthquakes and developing probabilistic earthquake forecasting and strong ground motion prediction strategies?
  - Is the master model significantly improved from year to year beyond relatively elementary models?

- *Data and Ideas*
  - Is the Center assuming the role of a clearinghouse for data and ideas pertaining to earthquake research and hazard mitigation?

- Is the Center effective in assimilating data and ideas not only from its own participants, but also from other researchers world-wide who are funded from other sources?
- What is the level of use by both Center and non-Center scientists and accessibility of the SCEC data center in Pasadena, as well as its compatibility with other data centers such as those operated by IRIS, the USGS, and UC Berkeley?
- What is the quality and quantity of new data (seismic, GPS, strong ground motion, fault zone geology, etc.) generated by SCEC, and the timeliness with which those data are archived by the data center for general use?
- Is the southern California earthquake catalog being properly maintained and updated?

- *Post-Earthquake Information*
  - Does the Center assume a responsibility for timely and accurate dissemination of data and other information to scientists, public officials, and the press following a damaging earthquake in southern California?
  - Does the Center develop effective communication and coordination of function with other organizations such as the USGS, SCEPP (Southern California Earthquake Preparedness Project), CDMG (California Division of Mines and Geology), CEPEC (California Earthquake Prediction Evaluation Council, and NEPEC (National Earthquake Prediction Evaluation Council) following a damaging earthquake?
  - Does the Center assume an effective role in the coordination of post-earthquake scientific investigations?

- *Other Funding*
  - Is the Center effective in its ability to leverage funding from other sources such as FEMA, foundations, business, and state and local government?

III. Education and Outreach

A. Objectives

The Center has a primary role in the education of individuals who will assume future leadership roles in earthquake research and hazard reduction. To this end it desires to train graduate students and post-doctoral fellows, and to invite interaction with visiting scientists from elsewhere in the U.S. and the world. The Center must also reach out to undergraduates and high school students in the southern California area as a means of encouraging careers in earth sciences, specifically, and science, in general. It must also be sensitive to the need to bring more women and minorities into the scientific mainstream, particularly given the present and projected population demographics of the southern California region. Finally, given the societal importance of earthquakes and earthquake hazard reduction in southern California, the Center has a responsibility to increase earthquake awareness among public officials, the media, the business community and the public at large, and to communicate with these groups, in understandable format, the Center's research findings.

B. Measures of Performance

- *Students, Post-docs, and Visitors*
    - What is the quality of graduate students, post-doctoral fellows, and visitors attracted to the Center?
    - Where do students and post-docs end up after their tenure with the Center? Are they in demand? Do they assume leadership roles?
    - What is the quality of the experience for visitors and hosting scientists under the visitors program?
    - Has the Center developed an effective program of outreach to high school students and teachers, perhaps in conjunction with SCEPP?
    - Has the Center provided an opportunity for college undergraduates to make meaningful contact with Center scientists and/or projects at the various core and participating institutions?

- *Women and Minorities*
    - Does the Center include participation by women and minorities?
    - What efforts are being made to recruit and/or interest such persons in the activities of the Center?
    - Are such persons involved in decision making?

- *Special Interest Groups*
    - Is there effective communication with groups such as emergency preparedness and response officials, corporate disaster planning coordinators, insurance underwriters, realtors, newswriters and newscasters, etc. who are concerned with earthquake awareness?
    - Do SCEC, SCEPP, and the USGS develop an effective working relationship in reaching out to the above groups?

IV. Technology Transfer

A. Objectives

The master model is the product of the Center. Its essence must be transferred to other scientists, earthquake engineers, emergency preparedness and response personnel, government officials and policy makers, the business community, the media, and the general public. SCEC will make use of workshops, technical reports, special publications, maps, and data bases to transfer the master model to the users. Forms of information transfer will necessarily be different for the different user groups. Newsletters and master model updates will issued on a regular basis. SCEC will team up with SCEPP in the transfer of information to the less technical user community. It will cooperate with the USGS and CDMG (California Division of Mines and Geology) in the transfer of more technical information.

B. Measure of Performance

- Are workshops held for the user groups? How effective are they?
- Are the publications which are required for technology transfer being produced by the Center?
- Are the master model products accepted and/or used by other scientists, engineers, private consultants, public officials, and the public at large?
- How universally applicable is the master model concept?
- Is the Center effective in increasing earthquake awareness in southern California and the rest of the nation?
- Does the Center have an impact on seismic policy in California and the nation as a whole?
    - Is it being used as a consultative body on matters pertaining to the study of earthquakes and how to use the results of such studies for earthquake hazard mitigation?
    - Does it help facilitate the implementation of federal and state programs in earthquake research?

VI. Institutional Support and Management

- Institutional Support
    - What is the level of institutional support at the core and participating institutions?

- Management
    - How effective is the management in keeping the Center focused, interactive and generally productive?
    - Are the scientific participants and officials at the participating institutions satisfied with the managers and management structure?
    - How is the Center management perceived by NSF, the USGS, and other outside organizations with which SCEC has relationships?

- Governing Boards
    - How effective are the Center Board of Directors, the Steering Committee, Group Leaders, and Advisory Council in providing guidance and oversight? Do these groups show a genuine interest in making the Center viable and productive?

- Research Groups
    - Are the research groups and group leaders effective in planning, organizing, carrying out, summarizing, and integrating the research activities and results?

- Funding
    - Have objective procedures been devised for distributing research funds to the various principal investigators, including the development of an overall scientific plan, and accounting for their expenditure vis-a-vis research productivity and scientific quality?

Southern California Earthquake Center

1991 Visitors and Post-doctoral Fellows

Visitor	Host Institution	Research Project
V. Keilis-Borok (Academy of Sciences of USSR) (Ph.D.-1947) and Tanya Levshina	UCLA	Precursor Phenomenology and Modeling
Peter Molnar (MIT) (Ph.D-1970)	UC-Santa Barbara	Rotation Tectonics and Crustal Shortening across the Transverse Ranges (Possibility of M8 Thrust Earthquake)
Geoffrey King (IPG, Paris) (Ph.D.-1970)	USGS/USC	Blind Thrust and Mechanics of Fault Zone Deformation
Minoru Takeo (ERI, Tokyo) (Ph.D.-1982)	Caltech	Strong Motion Simulation for Southern California
Gianluca Valensise (ING, Rome) (Ph.D.-1987)	UC-Santa Cruz	Terrace Topography and Palos Verdes Fault
Jian Lin (Woods Hole) (Ph.D.-1988)	USGS	Mechanical Analysis of Blind Thrust Fault Network in the Los Angeles Basin
Sergio Barrientos (Univ. of Chile) (Ph.D.-1987)	UC-Santa Cruz	Fault Segmentation Study Using Dislocation Model
David Scott (Oxford) (Ph.D.-1987)	USC	Role of Fluid in Mechanical Models of Earthquakes
Rachel Abercrombie (Reading) (Ph.D.-1991)	USC	Fault Mapping and Seismic Scaling Law in the Scale Range 1 m to 10 km

Group A: Master Model Construction and Seismic Hazard Analysis

Group Leader: Keiiti Aki

Probabilistic Seismic Hazard Assessment of the Greater Los Angeles Region	Peterson-Sykes-Jacob (Columbia)	A-1
Groundwork for a Master Model	Wesnousky (Nevada-Reno)	A-4
Development of a short-term prediction program and Master Model Definition	Minster and Agnew (UC-San Diego)	A-5
Seismic Hazard Due to Interacting Fault Segment	Cornell (Stanford)	A-6
Comparing Historic and Geologically Estimated Fault Slip	Jackson-Davis (UCLA)	A-7
Determination of Site-Specific Weak-Motion Amplification Factor for California	Aki and (USC)	A-9
GIS Working Group Report	Sammis (USC)	A-14
Digital Geologic Map Database for Southern California	Park (UC-Riverside)	A-16
Mapping participation in SCEC	Miller (UC-Santa Barbara)	A-19
Design and implementation of the Master Model GIS	Richard (UC-Santa Barbara)	A-22
Living with the San Andreas fault	McNally (UC-Santa Cruz)	A-23

A-1

Probabilistic Seismic Hazard Assessment for the Greater Los Angeles Region from Characteristic Earthquakes along the San Andreas and San Jacinto Faults Using Time-dependent and Poissonian Recurrence Models

Mark D. Petersen, Lynn R. Sykes, and Klaus Jacob
Lamont-Doherty Geological Observatory of Columbia University, Palisades, NY 10964

A probabilistic seismic hazard assessment is conducted for the greater Los Angeles region that compares hazard calculated using time-varying and Poisson recurrence models for characteristic earthquakes along the San Andreas and San Jacinto faults. The 60% probability of an event of magnitude 7.5 along the southern San Andreas fault estimated by the Working Group on California Earthquake Probabilities (1988) for the next 30 years is about two times larger than the Poissonian (average long-term) rate. We calculate the probabilities of exceeding pseudo-velocity response spectra (PSV) for large earthquakes ($M > 7$) along six fault segments defined by the Working Group (1988): the Mojave, San Bernardino Mountains and Coachella Valley segments of the San Andreas fault and the San Bernardino Valley, San Jacinto Valley and Anza segments of the San Jacinto fault (Table 1). We incorporate site response that we calculated from strong motion data for the 1971 (M_S=6.5) San Fernando earthquake for alluvial, soft-rock and hard-rock sites. Our data indicate that mean PSV amplitudes are about a factor 1.3 higher at 0.3 s, a factor of 2.0 higher at 1 s and a factor of 2.7 higher at 3 s on alluvium than they are on average hard rock sites (Table 2). The calculations indicate that the median 30-year probability of exceeding 20 cm/s at 1 s period for both time-dependent and Poissonian recurrence probabilities is greater than 20% for most of the greater Los Angeles region, excluding the coastal areas. The 30-year probability of exceeding 20 cm/s is particularly high in the San Bernardino area, exceeding 40% for time-dependent recurrence and 30% for Poissonian recurrence models in regions 30 km from the San Andreas or San Jacinto faults. Probabilities near San Bernardino are particularly high because the area is located close to the San Andreas and San Jacinto faults and because the area is located in an alluvial valley that may amplify the wave motion. Hazard curves are computed for both rock and alluvial sites in Los Angeles, Ontario, and San Bernardino using both time-dependent and Poissonian recurrence probabilities. These hazard curves indicate that the 30-year probabilities of exceeding 20 cm/s PSV at 1 s period for hard rock sites range from 20% near Los Angeles to 65% near San Bernardino for time dependent recurrence calculations (Figure 1). Uncertainties are high (up to 40%) for the computed hazard curves at those three sites and are caused primarily by the scatter associated with the attenuation function and the recurrence probability (Figure 2).

Table 1

Segment	recurrence probabilities, time-dependent	recurrence probabilities, Poissonian
Mojave (M7.5)	0.32	0.17
San Bernardino Mtns.(M7.5)	0.22	0.14
Coachella Valley (M7.5)	0.36	0.11
San Bernardino Valley (M7)	0.17	0.14
San Jacinto Valley (M7)	0.13	0.15
Anza (M7)	0.29	0.19

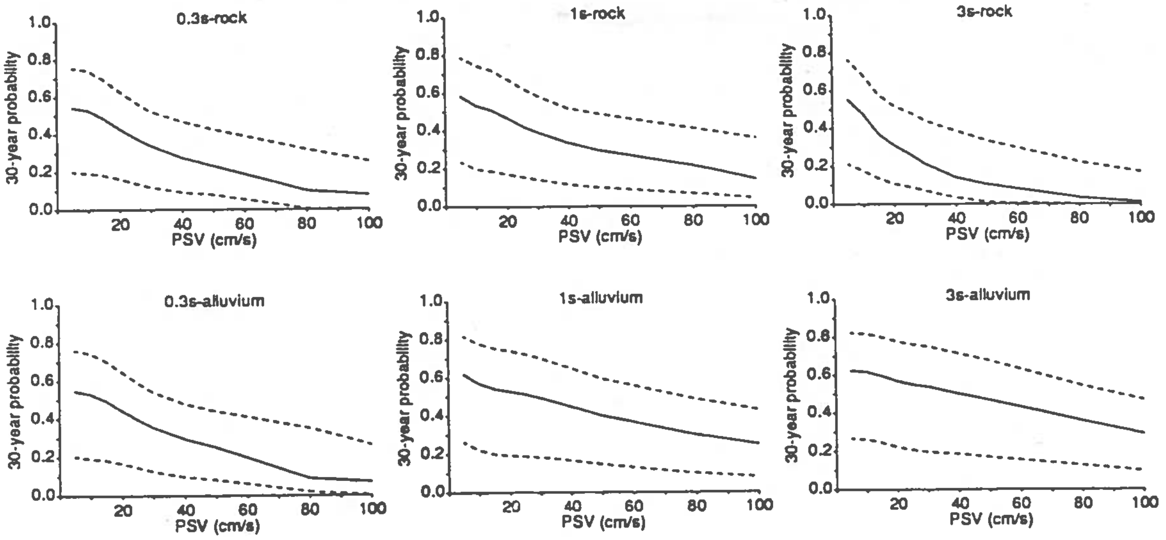
Table 2

Geology	0.3 s period amplification factor (standard deviation)	1 s period amplification factor (standard deviation)	3 s period amplification factor (standard deviation)
hard rock -igneous	1.2 (0.7)	1.2 (0.8)	0.6 (0.4)
soft rock -Tertiary	1.1 (0.2)	2.0 (1.4) *	2.0 (0.9)
alluvium -Quaternary	1.3 (0.7)	2.0 (0.8)	2.7 (1.0)

*observed amplification factor is 2.4, adjusted to 2.0 for hazard calculation.

A-2

(a) POISSONIAN PROBABILITIES



(b) TIME-DEPENDENT PROBABILITIES

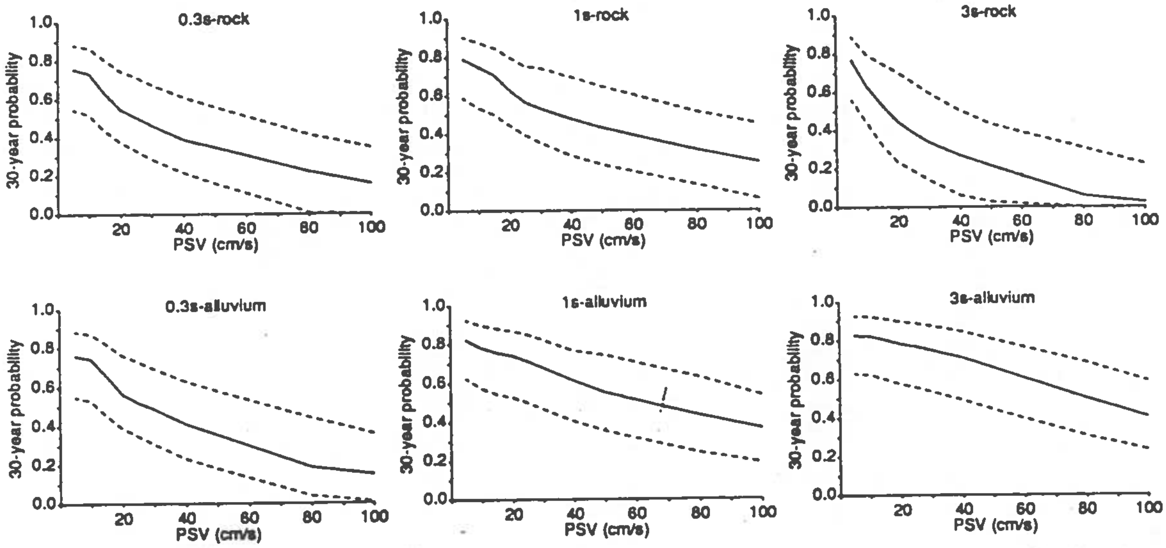


Figure 1. Hazard curves showing the median (solid curve), 85% (upper dashed curve) and 15% (lower dashed curve) confidence levels for a site in the city of San Bernardino for rock and alluvium sites at 0.3 s, 1 s, and 3 s periods. (a) hazard curves computed using poissonian recurrence probabilities as input. (b) hazard curves computed using time-dependent recurrence probabilities.

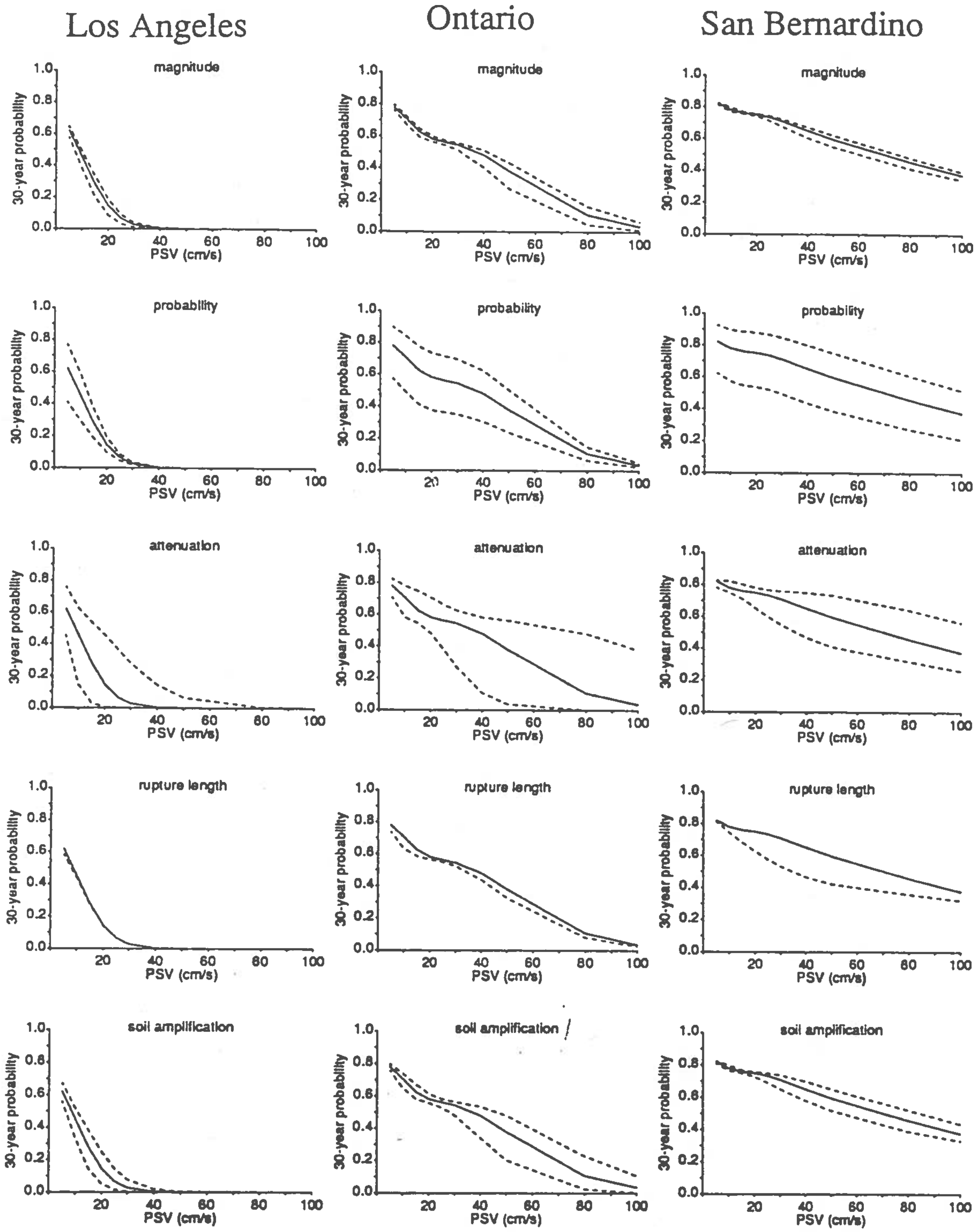


Figure 2. Hazard curves for the cities of Los Angeles, Ontario, and San Bernardino for alluvial sites at 1 s period computed by varying one input parameter while holding all other parameters constant. Median curves are solid, dashed curves obtained by increasing or decreasing the given parameter.

A-4

SCEC Progress Report: Groundwork for a Master Model
Period: April 1, 1991 to October 18, 1991
P.I.: Steven G. Wesnousky

The Southern California Earthquake Center has embarked upon an effort to develop a master model of seismic hazard for southern California. The underpinnings of the effort will be data describing the locations, slip rates, and paleoearthquake histories of active faults in the region. Hence, we have begun to synthesize the slip rates, paleoearthquake histories, and historical record of earthquakes along mapped faults and related seismogenic structures in southern California. To date, we have finished our synthesis of data bearing on the major strike-slip faults of southern California: The San Andreas, San Jacinto, Elsinore, Rose Canyon, Newport-Inglewood, and Palos Verdes fault systems. For each fault, we have prepared a written summary describing the results of paleoseismological studies for each fault zone, maps showing the sites of the respective studies, and a complete bibliography of the published literature describing the details of the particular studies (Appendix). Currently, we are placing the information in a tabular format that may (1) readily be input into a GIS data base and (2) used as the basis for constructing long-term seismic hazard maps. Subsequently, work will go toward completing a similar update for remaining faults and other seismogenic structures (e.g. blind thrusts) in the region.

. On a separate front, we have also began looking at characteristics of the earthquake frequency distribution for particular faults by combining paleoseismological data with historical and instrumental earthquake statistics. Understanding the shape of the b-value curve for individual faults is needed to assess the hazard due to moderate to large earthquakes which are not primary surface rupturing events. Our observations to date suggest that the San Andreas and Garlock faults, the faults with greatest cumulative offset are characterized by a 'characteristic earthquake' frequency distribution whereas the San Jacinto and Newport-Inglewood faults show a classical Gutenberg-Richter distribution.

Finally, an initial digitized data set of faults and slip rates has been provided to Steve Park at UCR to incorporate into a GIS data base and I have provided the output of initial hazard map calculations to Lucy Jones so that she may incorporate aspects of probability gain due to the occurrence of possible foreshocks into hazard map calculations.

A-5

Southern California Earthquake Center

Annual Activity Report

Jean-Bernard Minster
Duncan Agnew
Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography,
University of California, San Diego, La Jolla, CA 92093-0225

Dr. Minster, as member of the Board of Directors representing the Scripps Institution of Oceanography (UCSD) attended all Board meetings but one, and all monthly seminars but one (in each instance of an absence, UCSD was represented by Dr. Agnew). He also organized and hosted the July, 1991 monthly seminar series at the Institute of Geophysics and Planetary Physics, in San Diego.

Drs. Minster and Agnew both participated in the activities of the Working Group on the Master Model, and contributed a presentation to the working group meeting of July 29, 1991, discussing how the master model definition should be refined in terms of its practical applications.

Dr. Minster initiated, in collaboration with Dr. Archuleta of UCSB, the drafting of a Memorandum of Understanding between SCEC member institutions, to coordinate the use of portable (PASSCAL) instrumentation for field experiments and for rapid response to earthquakes. This Memorandum of Understanding should be followed by another one between SCEC and the Incorporated Research Institutions for Seismology (IRIS), outlining modes of cooperation between SCEC and the IRIS PASSCAL program in the use of portable instruments in southern California. After the Sierra Madre earthquake, Dr. Minster and Dr. F. Vernon of UCSD deployed four portable broadband (STS-2) stations in the epicentral area. The data collected in this deployment was rather sparse, in view of the paucity of aftershocks, but the experience pointed to the need for a more formal earthquake response plan. This observation was transmitted to SCEC in the form of a memo suggesting the formation of an ad hoc working group to develop such a plan.

Dr. Agnew has addressed the question of the completeness of the pre-instrumental earthquake record for southern California. This involved preparing a new version of the Evernden algorithm for predicting seismic intensities (available to the working group for using in predicting future earthquake effects), computing the intensity distribution for specific events, and comparing these with the recorded intensities--or, for hypothetical events, those that might have been recorded (which required a re-examination of the sources for the historical catalogs). The result shows that where constraints are available from paleoseismology these are almost always better than the historical record can provide. The intensities reported for the event of 8 December 1812 are consistent with a rupture on the San Andreas fault near Wrightwood, extending some distance along the fault from this point. Discussions have also been held with Dr. Lucy Jones on the application of the foreshock probabilities to a larger suite of faults in southern California than those already studied.

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Southern California Earthquake Center
Annual Report: Feb. 1, 1991 to Jan. 31, 1992

Prof. C. Allin Cornell, P.I.
Dr. Steven R. Winterstein, P.I.
Department of Civil Engineering
Stanford University

Subject: Seismic Hazard Due to Interacting Fault Segments
Funded Period: Oct. 1, 1991 - Jan 31, 1992

The Center is committed to making increasingly more accurate probabilistic seismic hazard estimates for sites in Southern California. The current seismic hazard methodology includes at most renewal recurrence models of independent faults and fault segments, coupled with ground motion prediction equations. Our research will extend the models to recognize that there is mechanical coupling between fault segments on the same and neighboring faults, and that slip on one fault segment may accelerate or retard the events on other segments thereby increasing or decreasing the estimate hazard contributed by those segments.

The work extends past analytical recurrence work by the investigators (e.g., Cornell and Winterstein; BSSA, 1988) and work which has been in progress through a Ph.D. student, S. C. Wu, in cooperation with USGS Drs. James Dieterich and Robert Simpson. Indeed, primitive notions of this work (in a fault-recurrence rather than a site-hazard form) appeared in an Appendix of the 1990 Bay Area NEPEC Working Group report, a group in which Cornell and Dieterich both served.

We approach the problem (1) from the perspective of segments as the atomic unit, because this creates the possibility of verification and application, and (2) from the phenomenological perspective (e.g., relating segment interactions through increments to stochastically modeled inter-event times rather than explicitly as stress state changes.) The focus will be on development and exploration of recurrence and site-oriented hazard models, analytically and via simulation as necessary.

Further the work should be consistent with other SCEC workers, e.g., the hazard mapping of Wesnousky and Jones, on one hand, and the non-linear, multi-mass slider dynamics of Jackson, Kagan and others, on the other.

Some preliminary results have been presented orally at the International Conference on Stochastic Mechanics in Corfu, Greece, September, 1991. We are preparing a paper based on that presentation for submission to BSSA.

Student: Ph.D. student funded for four months: S. C. Wu
Cooperating Investigators: James Dieterich and Robert Simpson, USGS, Menlo Park

COMPARING HISTORIC AND GEOLOGICALLY ESTIMATED FAULT SLIP

DAVID D JACKSON

October 24, 1991

We compared the fault slip implied by the historic earthquake record with the geologically estimated rate of slip, and with that predicted by plate tectonics. Our purpose is to see whther the release of seismic moment agrees with geological predictions, to determine whether seismicity is stationary, and to determine whether certain regions or faults are presently loaded, ready to suffer earthquakes.

We used the method of Wesnousky, 1986; we calculated predicited moment rates on each of about 100 fault segments based on their geologic slip rate and the length of the segments, which influences the size of earthquakes which whould occur there. We compared these numbers with the moment released in historic earthquakes above about magnitude 6. The results are summarized in Table 1:

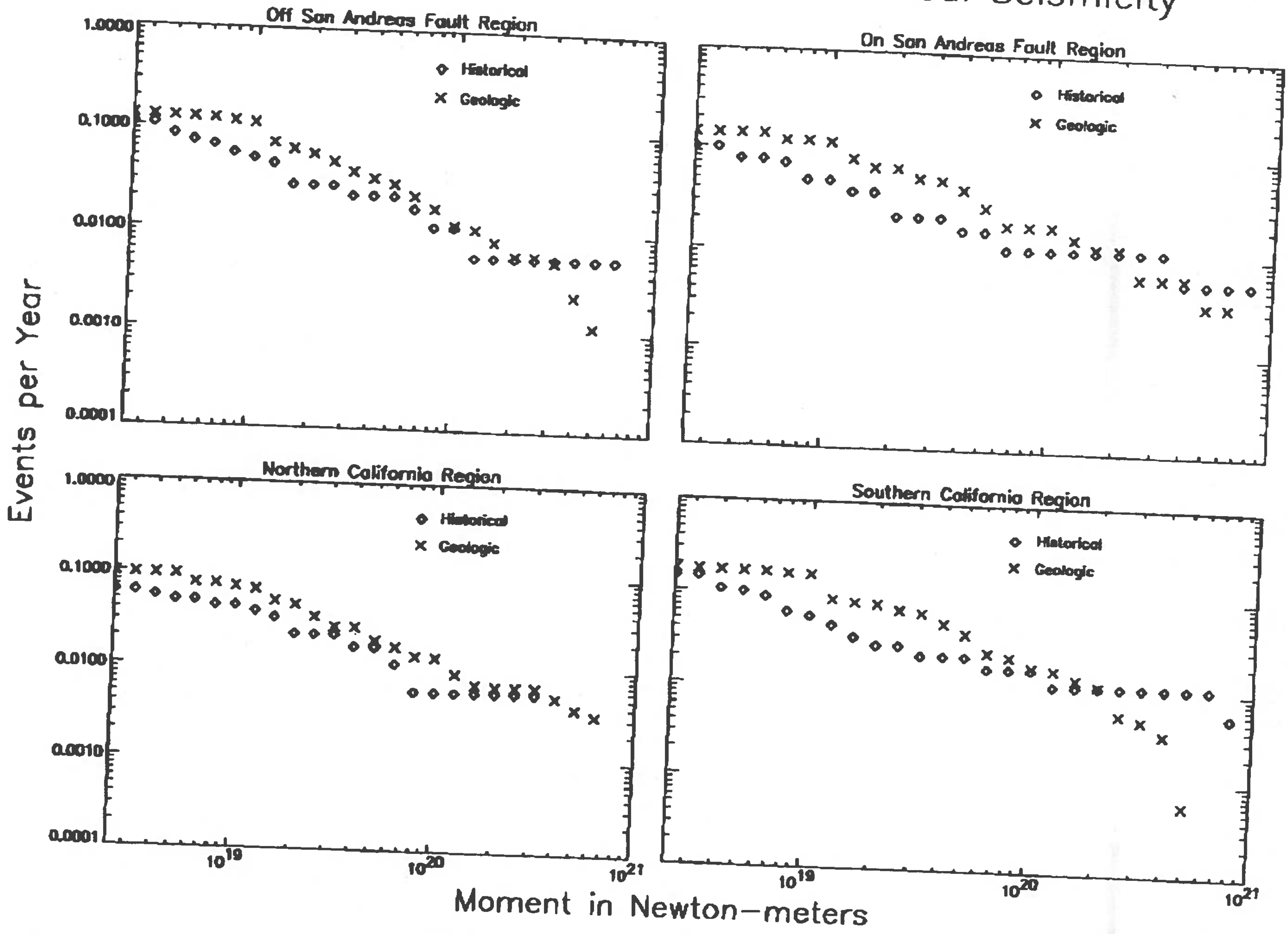
Table 1 Seismic moment release, 10^{18} Nm/yr

Region	Dates	Historical	Geological	Plate Tect
All Calif	1810-1990	14	15	34
All Calif	1810-1933	18	15	34
All Calif	1933-1990	6	15	34
N Calif	1810-1990	4	6	13
S Calif	1810-1990	10	8	20

The cumulative distribution of moment for earthquakes above a certain threshold is shown in the figure.

The results show that Most of the historic moment release has been in the south (1857, 1872, 1952); Neither northern nor Southern California has had enough earthquakes to keep up with the geological rate or the plate tectonic rate, but Northern California is further behind. The rate of seismic energy release has also been much slower since 1933, when instrumental recording became routine. Thus the historic record, especially that since 1933;, implies that the rate of occurrence of large earthquakes must increase in the future, or signifcant aseismic slip must occur. Since this aseismic slip is not observed geodetically now, it must be episodic if it occurs.

Comparison of Geologic vs. Historical Seismicity



A-8

A-9

Determination of Site-specific Weak-motion Amplification Factor for California

K. Aki and F. Su, *Dept. Geol. Sciences, Univ. of Southern California, Los Angeles, CA, 90089-0740*

The weak motion site amplification factors at the frequencies of 1.5, 3, 6, and 12 Hz have been determined using 132 well-calibrated stations of the USGS seismic network in Central California from coda waves of 185 local earthquakes (Su et al., 1991). The results show strong correlation between site amplification factors and surficial geologic age of the station. Fig. 1 is the results which shows the mean site amplification factors versus median geologic age for five station site groups: (1) Quaternary sediments, (2) Pliocene sediments, (3) Miocene sediments through Cretaceous Marine sediments, (4) Franciscan Formation and Mesozoic granitic rocks, and (5) Pre-Cretaceous metamorphic rocks.

We then extended the same work to the Southern California region and determined site amplification factors at 158 stations of the USGS-CALTECH seismic network. Figure 2 shows the results for Southern California. By comparing Figures 1 and 2, we can see that the general trends for each frequency in these two regions are almost the same, although the standard error for Southern California is larger than that of Central California since the station surficial geology is more complicated in Southern California.

Our results from both Central and Southern California show that younger sites have greater amplification at all frequencies, although the age dependence is stronger for lower frequencies. This is in contrast to the strong motion amplification factor which becomes greater at rock sites than soil sites for frequencies higher than about 5 Hz, suggesting a pervasive non-linear site effect.

Figures 3 and 4 give the spatial distribution of the site amplification factors of Southern California for 1.5 and 12 Hz, respectively. As shown in these two figures, we used seven symbols to indicate seven different site amplification ranges. We found that the Imperial Valley region has very high site amplification, especially for low frequencies.

The relation between weak motion site amplification with geologic age provides a simple way of estimating site effect at a specific site with known surficial geology. The weak motion site amplification results are important for earthquake hazard analysis, seismic zonation, as well as for the comparison of the strong motion site amplification results in understanding the nonlinear behavior of sediment sites.

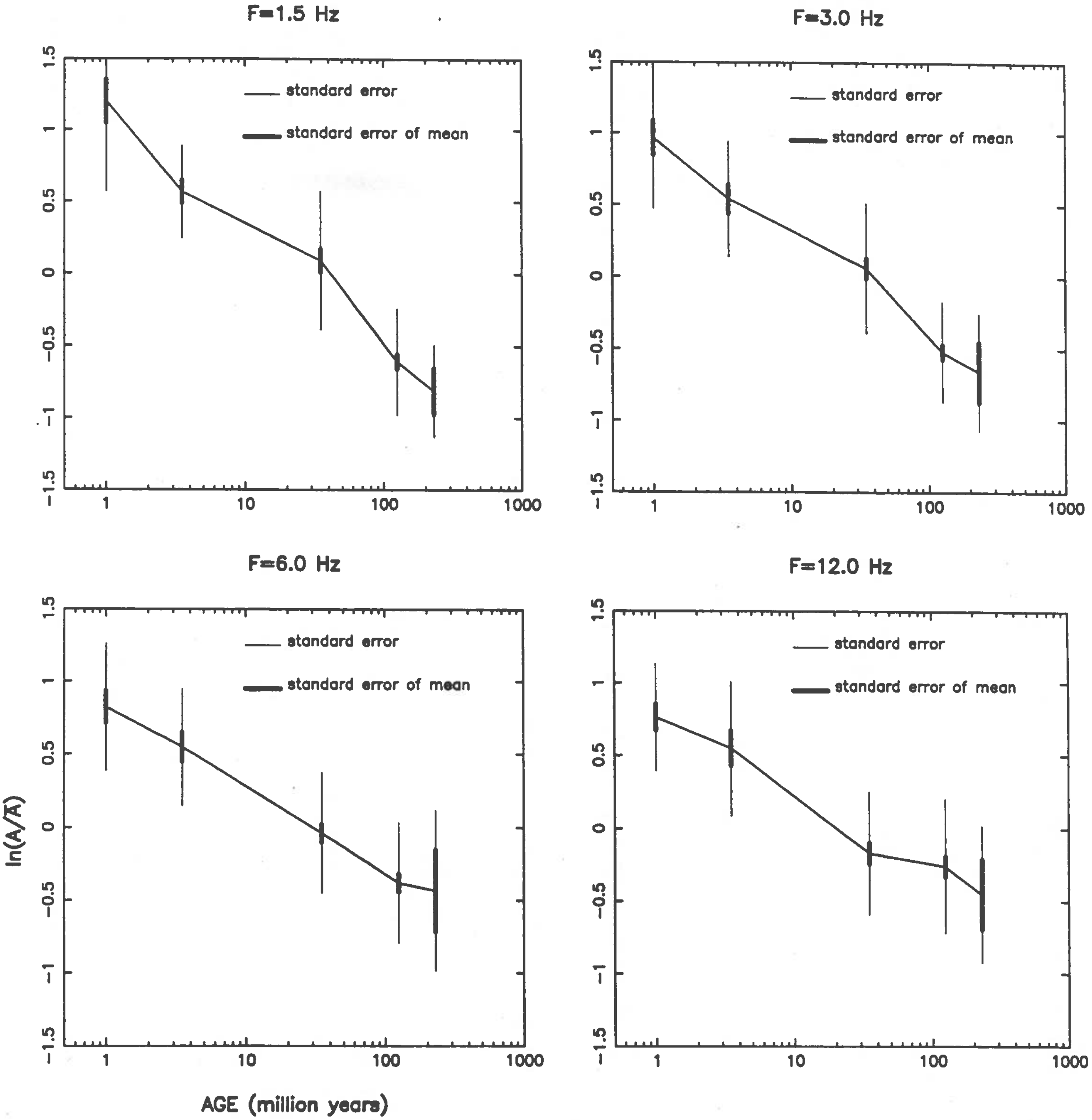

F=1.5 Hz
F=3.0 Hz
F=6.0 Hz
F=12.0 Hz
standard error
standard error of mean
ln(A/Ā)
1.5
1
0.5
0
−0.5
−1
−1.5
1
10
100
1000
AGE (million years)

fig. 1

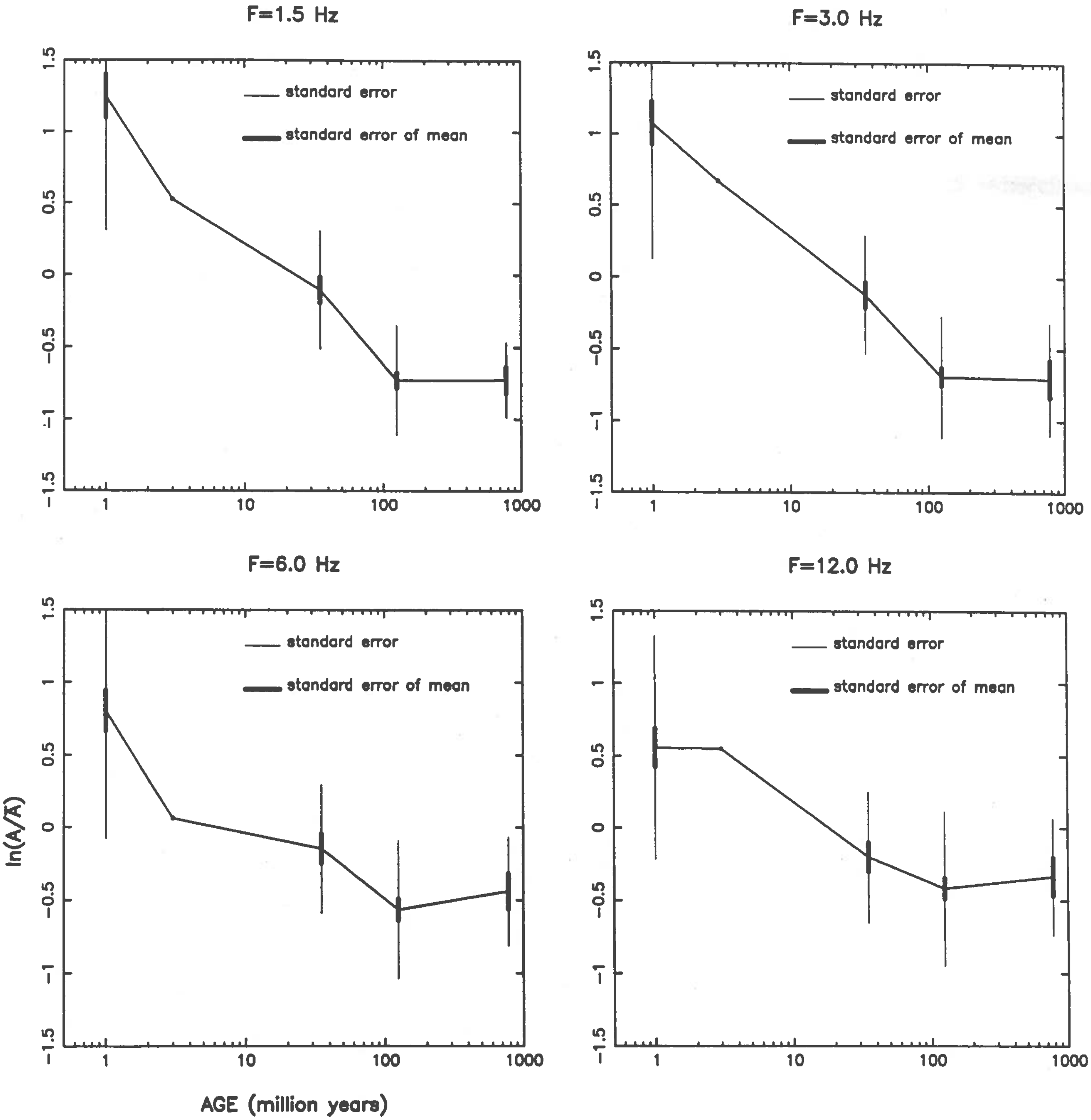

F=1.5 Hz
F=3.0 Hz
F=6.0 Hz
F=12.0 Hz
standard error
standard error of mean
ln(A/Ā)
1.5
1
0.5
0
-0.5
-1
-1.5
1
10
100
1000
AGE (million years)

fig. 2

SOUTHERN CALIFORNIA

SITE EFFECT (F=1.5 Hz)

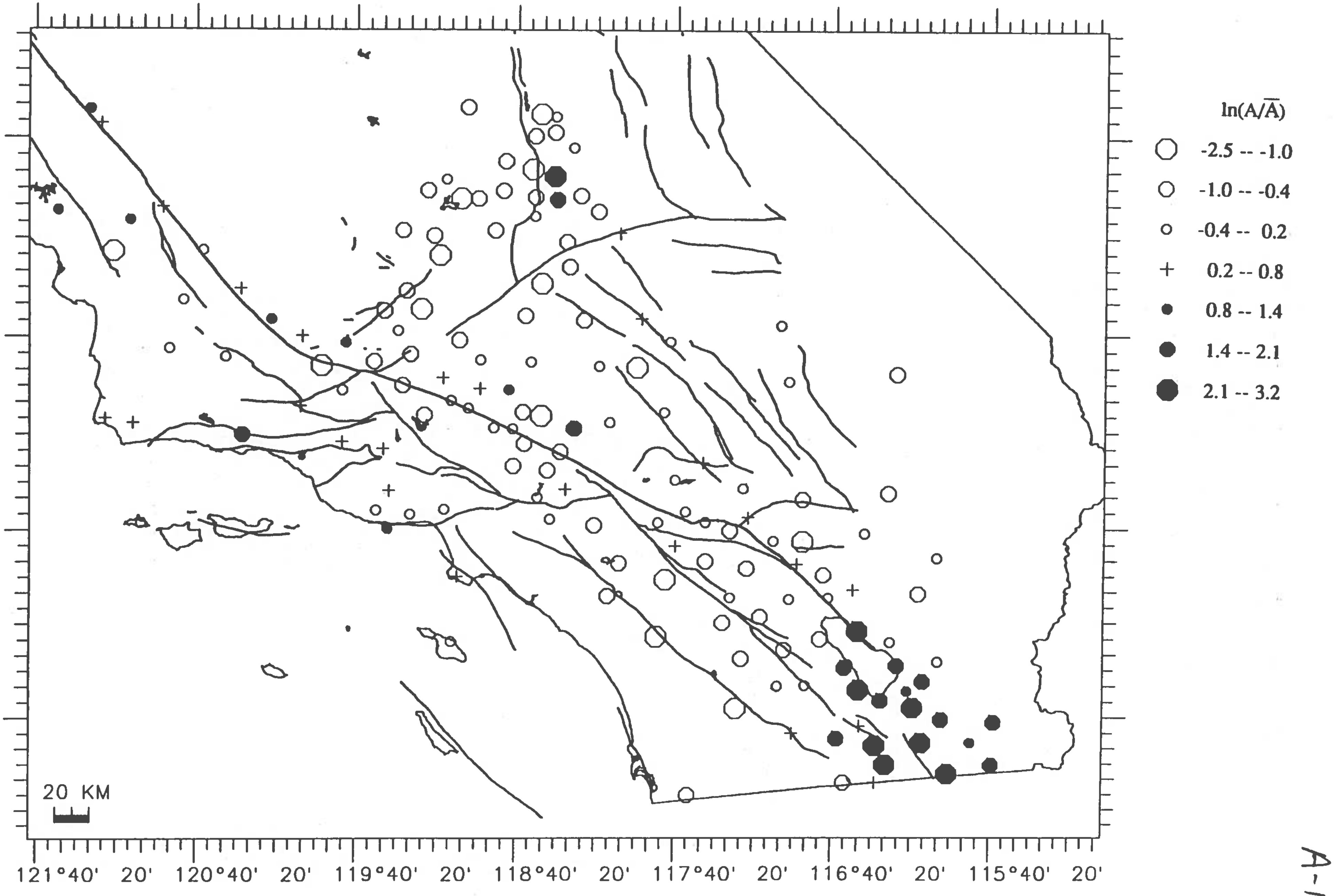


fig. 3

A-13

SOUTHERN CALIFORNIA

SITE EFFECT (F=12.0 Hz)

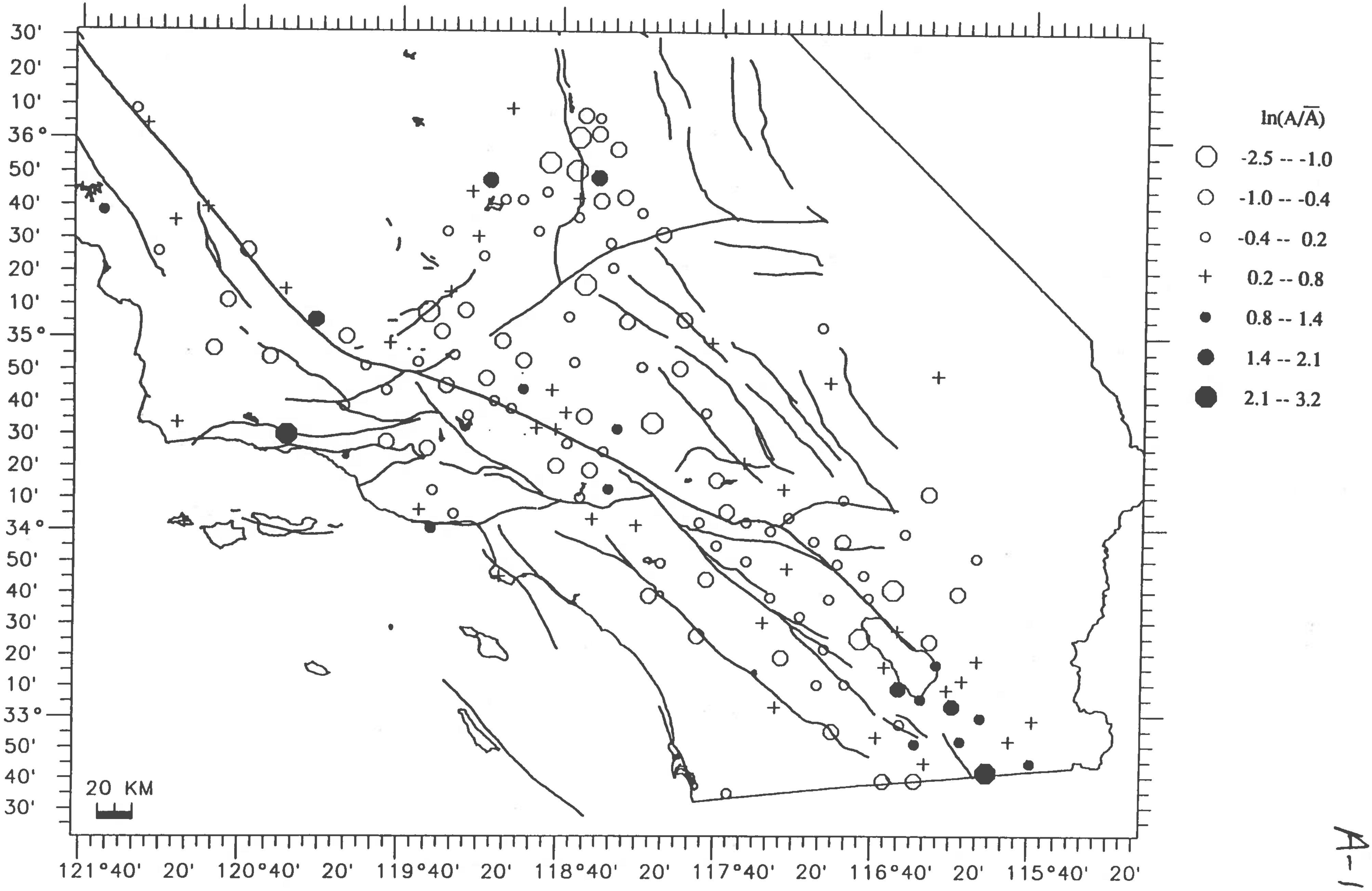


fig.4

A-14

GIS Working Group Report 22 October, 1991

Charles G. Sammis, Steve Park, Steve Miller, and Steve Richards

We have chosen ARCINFO as the principal GIS data base for the center. This program allows the overlap and display of multiple data sets such as geology active faults, topography, depth to water table, etc. It also allows the calculation of spatial variables based on these data an is thus well suited to the assessment of seismic hazard. The additional overlay of infrastructure such as highways, bridges, pipelines etc. makes it an ideal vehicle for interaction with government planning agencies.

ARCINFO is currently up and running at UC Riverside, UC Santa Barbara, and Caltech - we are installing it later this week at USC. We chose this database for the following reasons:

1) It is the industry standard in the geography community. Many universities have ARCINFO in their geography departments and even offer courses in its use. It is widely used by government agencies at all levels, and maps of the infrastructure in Southern California already exist.

2) It is currently being used by the USGS to produce 1:100,000 geologic maps of Southern California. Doug Morton plans to have 20 sheets completed (with updated geology) by 1995.

ARCINFO does have some drawbacks:

. 1) In its current form it is not user friendly. ESRI (the company which supplies the program) is currently testing a menu driven version which should eliminate this objection. Also, the USGS has developed a front-end program called ALACARTE which simplifies the compilation of geological data bases.

2) It is not a true 3-d database. It has the capability to drape map information over topography, but not to visualize true 3-D data sets. Our plan for dealing with this problem is as follows:

a) ARCINFO uses the ORACLE database which is true 3-D.
b) ESRI is developing a true 3-D GIS which we will use when it is released
c) As a stopgap, we will work with STARDENT and/or WAVEFRONT to produce 3-D visualizations of center data as required. These systems can use the ARCINFO data files.

Current projects

Implementation of ARCINFO

In order to overlay maps they must contain reference coordinates. This is done using a "tic file". Steve Park has created this file based on the corner coordinates of the 7 1/2 minute quadrangle sheets. Steve Park, in collaboration with Doug Morton at the USGS has also produced an attribute code for labeling the geology. The group feels that it is very important for the center to establish a standard for such labeling so that maps produced by government geologists will be compatible with the center database.

We plan to store the database in read-only format at Caltech. Other investigators are free to use any of the data layers as they see fit.

Collection of Database layers

We are currently working on the following layers:

1) Active faults - we have Wesnowski's files
2) All faults
3) Simple geology - Alluvium vs bedrock
4) Physiographic boundaries - in hand at Caltech
5) Topography - in hand at UCSB
6) Water table
7) Infrastructure
8) Detailed geology near SanBernardino as an example area - Steve Park
9) Detailed mapping along the SanAndreas - Kerry Sieh

Project: Digital Geologic Map Database for Southern California
P.I.: Stephen K. Park
Institution: University of California, Riverside
Date: October 19, 1991

Results from this project fall into three categories: organization; database design; and specific results for the San Bernardino basin.

We have selected ARC/INFO as the geographic information system (GIS) for SCEC and have negotiated an institutional contract with Earth Systems Research Institute (ESRI) for the purchase of multiple copies of ARC/INFO. Anyone in SCEC can now obtain a copy for approximately $1500, and manuals are $350. We have also formed a working group for the geologic database as a subset of the Working Group A and hold regular, if infrequent, meetings to discuss progress. Some effort is spent in evaluation of other digital data sets, such as Wesnousky's slip data, for eventual inclusion in the Center's database. We are now incorporating Wesnousky's data into the geologic maps, for example. In addition, a map at 1:750000 showing the geology of southern California is available. This map distinguishes between Quaternary, Tertiary, and pre-Tertiary units and spans the region between 32° N and 36N and between 114W and 122W.

ARC/INFO stores data in two ways. The geographic features (lines, points, and polygons) are stored in latitude and longitude in our database. Linked to the geographic features are attributes which tell the user what is the feature. Design of a standardized coding system for attributes is a high priority for SCEC because this will determine what research can be done with the resulting database. I have developed a draft of an attribute system based on an earlier one used by the USGS in Maine, and we are now revising this coding system. The final result will also be used by Doug Morton (USGS-UC Riverside) for the regional mapping he is supervising. Primary emphases in the coding system will be flexibility and room for growth as new research directions are realized.

ARC/INFO has been temporarily installed on a borrowed Sun workstation at UCR. I currently have three of the six quadrangles for the San Bernardino basin (Figure 1) in digital form, and the remaining three will be done by year's end. An example of a completed quadrangle (Redlands) is shown in Figure 2. At that point, the geology at a scale of 1:24000 will be available for the region between the San Jacinto and San Andreas fault zones. The digitized geology is a compilation of both published and unpublished maps and is thus unavailable anywhere else than from SCEC. We will pursue two avenues of research in this next year. First, subsurface geology and maps of the water table will be incorporated into the database in order to examine liquefaction potential in the San Bernardino basin. Second, I will work with Steve Wesnousky in implementing his seismic hazard analysis for the basin on a much smaller scale than he has used previously. My highest priority for this next year is to stabilize the map center operation at UCR by obtaining equipment dedicated to SCEC. All I currently have is a disk drive attached to the borrowed workstation.

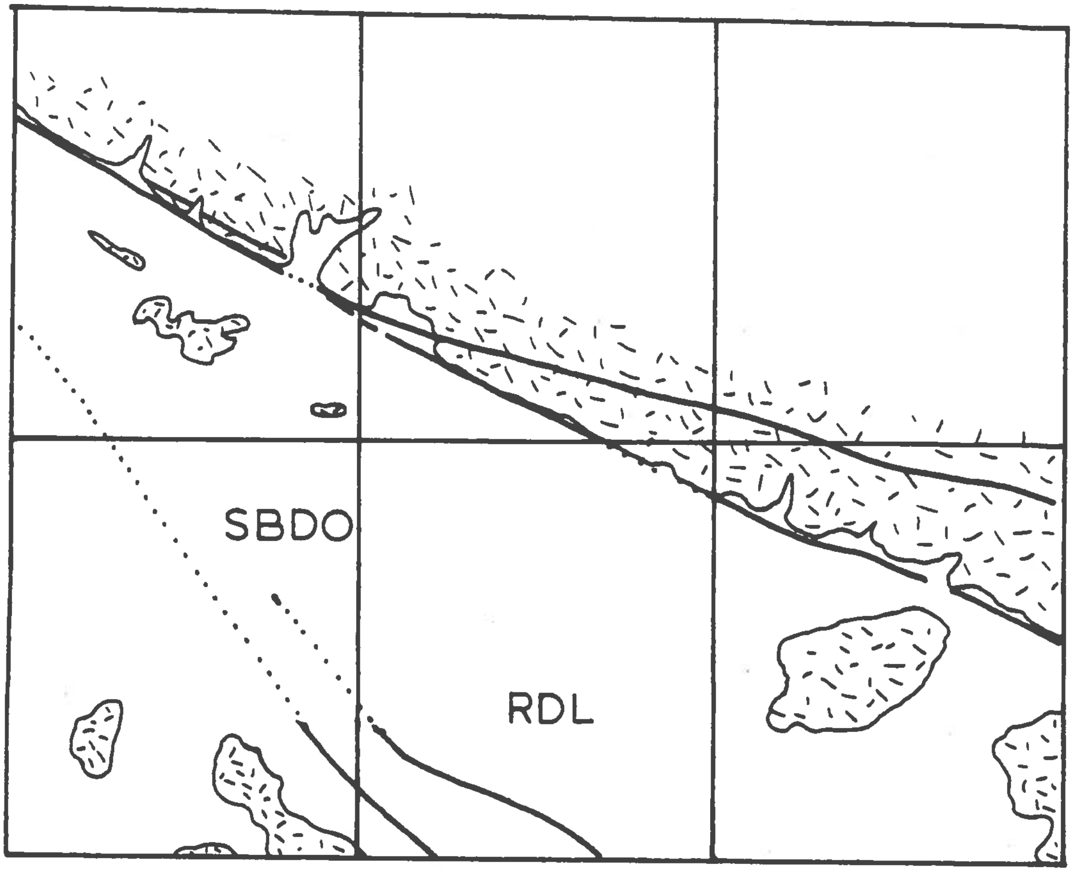


Figure 1 - Location map for study area. Basement rocks are shown with pattern, and faults are dotted where inferred. Symbols used are: SBDO, San Bernardino; and RDL, Redlands.

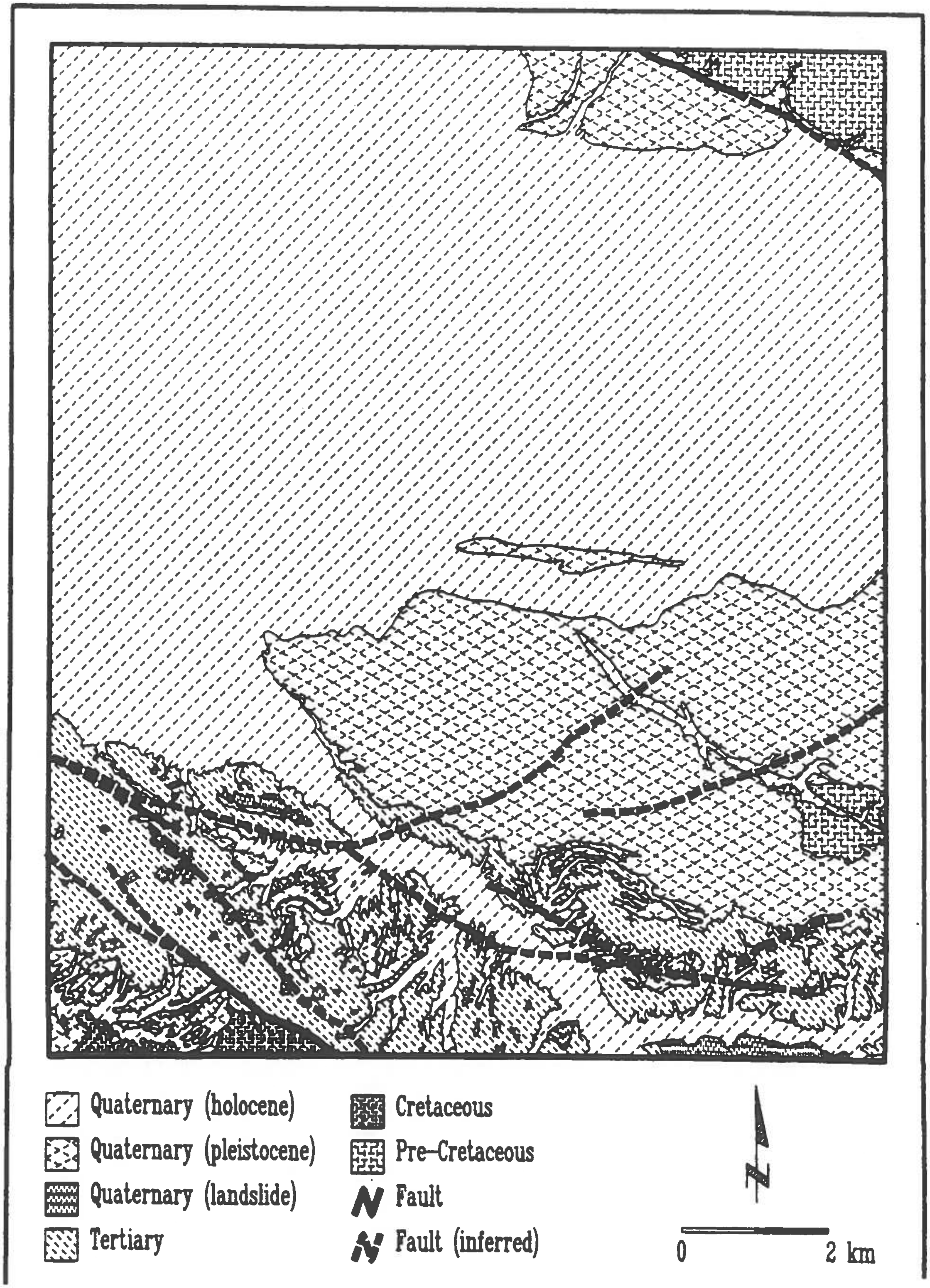


Figure 2 - Digital map for Redlands 7.5' quadrangle. Quaternary units have been lumped together for presentation; the stored map is more complicated.

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Year 1 Annual Report, Oct 22, 1991

Mapping Participation in the SCEC

Stephen P. Miller

Dept. Geological Sciences, UCSB, Santa Barbara, Calif. 93106

805-893-2853, miller@sbugel.geol.ucsb.edu

During the first partial year of operation (May-October, 1991) we have established a SCEC GIS mapping and 3-D visualization facility at UCSB. Color output is available on a film recorder and on a 36 inch electrostatic plotter. The following goals have been accomplished:

1. ARC/INFO GIS software has been installed on a Sun Sparcstation 2 GX computer, including all available software options, and has been upgraded to a multiple user license. The machine is accessible on the Internet as rapa.geol.ucsb.edu (128.111.108.22). See Stephen Miller for the SCEC username and password. Before sending a plot, SCEC users need to telephone 805-893-4704 to make sure the plotter is actually turned on.

2. A 670 MB disk has been added to the Sun workstation for SCEC usage.

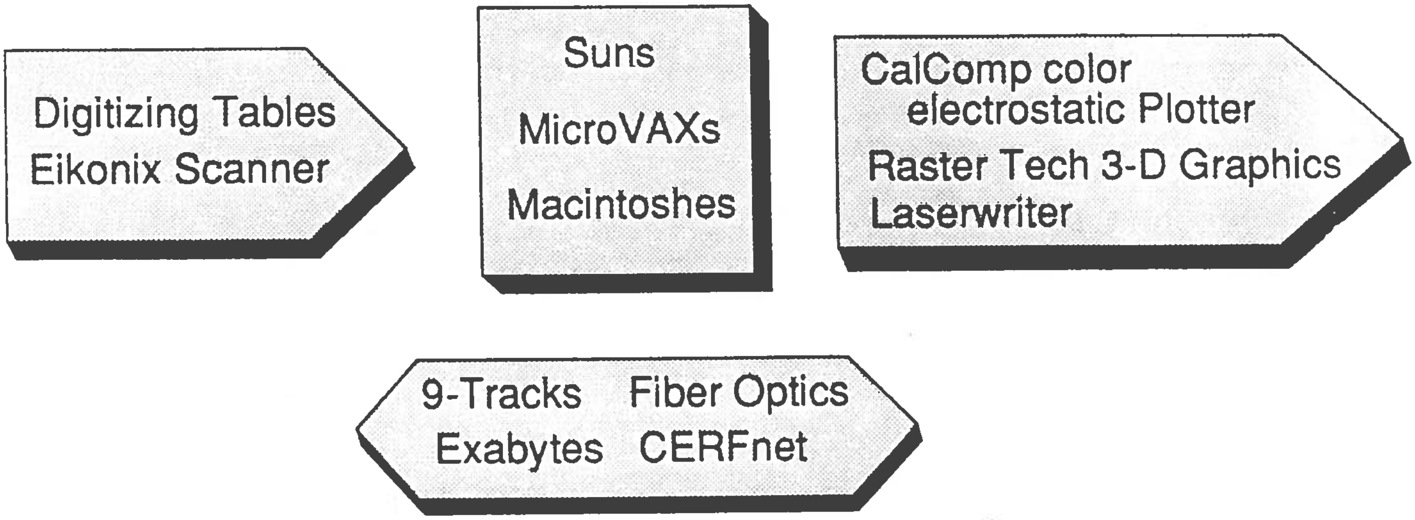
3. A parallel interface has been installed to enhance throughput between the Sun and the CalComp 5835XP color electrostatic plotter.

4. ARC/INFO coverages have been exported from UCR, and preliminary maps have been rendered on the color electrostatic plotter, depicting Southern California fault and basement types.

5. Software has been developed to read USGS 1:250,000 DEM topography grids. Four panels have been combined, along with hand-digitized seafloor bathymetry, to create a composite LA basin terrain model. The sample spacing is approximately 90 m.

6. 3-D color shaded relief images of the LA basin are being rendered on the UCSB Raster Technologies graphics system, with output to a film recorder.

UCSB Mapping Hardware



Digitizing Tables
Eikonix Scanner

Suns
MicroVAXs
Macintoshes

CalComp color electrostatic Plotter
Raster Tech 3-D Graphics
Laserwriter

9-Tracks
Exabytes
Fiber Optics
CERFnet

UCSB Mapping Software

Color-fill contouring

DI-300

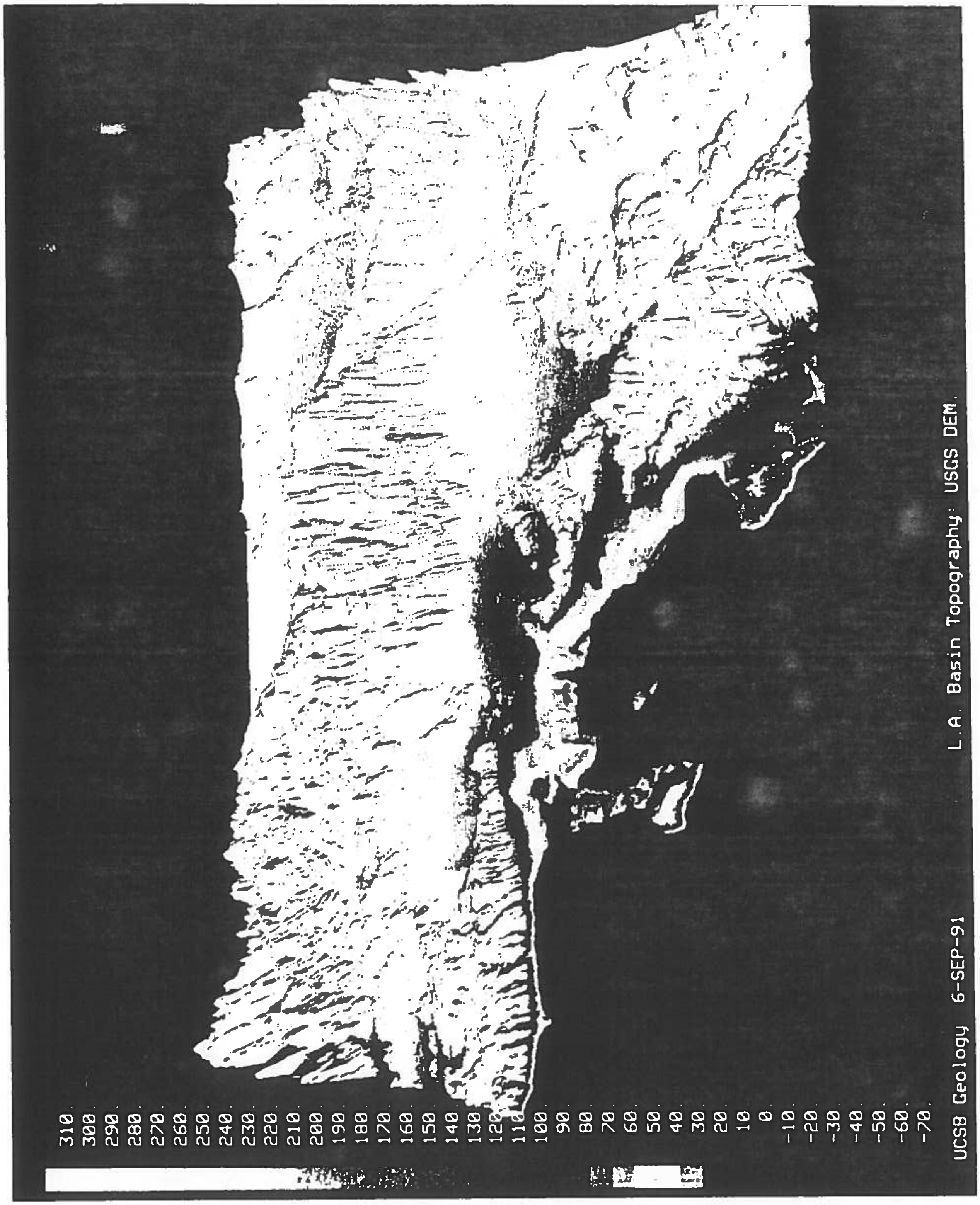
3-D and 4-D viewing (realistic light sources, shading)

L-DGO GMT

Adobe Illustrator

ERDAS

ARC/INFO



3-D imaging of the LA basin, based on composite USGS 1:250,000 DEM topography grids (work in progress). Seafloor data are being digitized to provide a complete gridded representation.

INSTITUTE FOR CRUSTAL STUDIES

SCEC Progress Report

Design and Implementation of Master Model GIS

Stephen M. Richard, PI

Oct. 17, 1991

During year one, I have developed an method of implementing the seismic hazard assessment techique of Wesnousky (1986) using Arc/Info. A summary of the algorithm to be implemented and a discussion of the nature of the data structure were presented to the group at the July SCEC meeting, with a request for comments. As none were received, I am proceeding with the implementation at present. I attended meetings of the Master Model group at U. C. Riverside and at USC to discuss the nature and goals of the database structure. Between now and the end of January the implementation of the Wesnousky method will be completed, and his data base for active faults will be integrated into the Master Model Arc/Info database being built jointly at UCSB, USC and UCR.

UNIVERSITY OF CALIFORNIA, SANTA BARBARA, CA 93106-1100 (805) 893-8231 FAX (805) 893-8649

A-23

Living with the San Andreas - K. McNally

Cooperative Arrangement Between SCEPP and SCEC:

SCEPP is to form a cooperative agreement with the Southern California Earthquake Center to assist the Center with its outreach program. In the broader sense, outreach consists of the translation and transfer of scientific information generated by Center investigators to practitioners. These practitioners include design professionals, hazard managers, educators, journalists, risk managers, policy makers/elected officials and other research scientists. More specifically, outreach would be implemented through the assignment of staff and development of a work program mutually agreed upon by SCEPP and the Center.

A basic element of the proposed arrangement is the assignment or hiring of a professional staff employee whose position would be funded by the Center. This person would provide liaison between SCEPP and SCEC and would work with a multi-disciplinary advisory committee to formulate a general plan for SCEC outreach.

The outreach program will be built around a number of anticipated Center outputs or products. These outputs include new scientific information which will contribute to a better definition of seismic risk in southern California. This risk information may take the form of revised earthquake probabilities or new information on faults, liquefaction potential and soils amplification. The Center will be heavily involved in the analysis of all significant earthquakes which occur in the region. They will also follow developments and work toward improved earthquake prediction techniques.

The outreach program may include:

> Workshops for scientists regarding the needs of practitioners and the public which can be met by Center research;
>
> Earth science education for practitioners and the public (primary, secondary, undergraduate and continuing education). This program element also includes curriculum development and mechanisms to update curriculum;

Development of a Geographic Information System to merge SCEC work with other public/private sector use of GIS (a workshop designed to coordinate the development and use of these systems is a possibility);

Conduct special workshops and seminars to translate scientific information for various organized groups concerned with earthquake preparedness and response (e.g. BICEPP, Schools Task Force, the Emergency Preparedness Commission, etc.);

Develop an earthquake response plan for the Center and identify what role SCEC could play in the aftermath of an earthquake in assessing short-term earthquake risk;

Outline a dissemination strategy for translated scientific knowledge; and

Coordinate and publish periodic newsletters and other communications with constituents. These publications may include a Center brochure, a quarterly newsletter, special reports on recent earthquakes and a non-technical report on current seismic potential for the public.

SCEPP and SCEC have also jointly produced a bulletin on the Sierra Madre earthquake which contains seismological, geotechnical and sociological information on the June 28th earthquake. SCEPP and SCEC will collaborate on a publication addressing the earthquake potential in southern California.

SCEC/SCEPP Workshops:

SCEPP education of SCEC scientists as to how their research can be used in the outside world. Would include participation of representatives from user groups.

Development of GIS. Application and integration, compatibility with local government, private sector, USGS, CDMG, etc.

Public schools (K - 12). Assess curriculum development, mechanisms to provide updates, and extent of scientific involvement which might be desirable.

Work out an information dissemination strategy. E.g, workshops, seminars.

A-25

Plan to develop written communications and periodic dissemination of Center products. E.g., earthquake bulletins, what is SCEC?, general quarterly newsletter, next big earthquake document.

Group B: STRONG GROUND MOTION PREDICTION

Group Leader: Ralph Archuleta

B-1

Determination of Site-specific Weak-motion Amplification Factor for California

K. Aki and F. Su, *Dept. Geol. Sciences, Univ. of Southern California, Los Angeles, CA, 90089-0740*

The weak motion site amplification factors at the frequencies of 1.5, 3, 6, and 12 Hz have been determined using 132 well-calibrated stations of the USGS seismic network in Central California from coda waves of 185 local earthquakes (Su et al., 1991). The results show strong correlation between site amplification factors and surficial geologic age of the station. Fig. 1 is the results which shows the mean site amplification factors versus median geologic age for five station site groups: (1) Quaternary sediments, (2) Pliocene sediments, (3) Miocene sediments through Cretaceous Marine sediments, (4) Franciscan Formation and Mesozoic granitic rocks, and (5) Pre-Cretaceous metamorphic rocks.

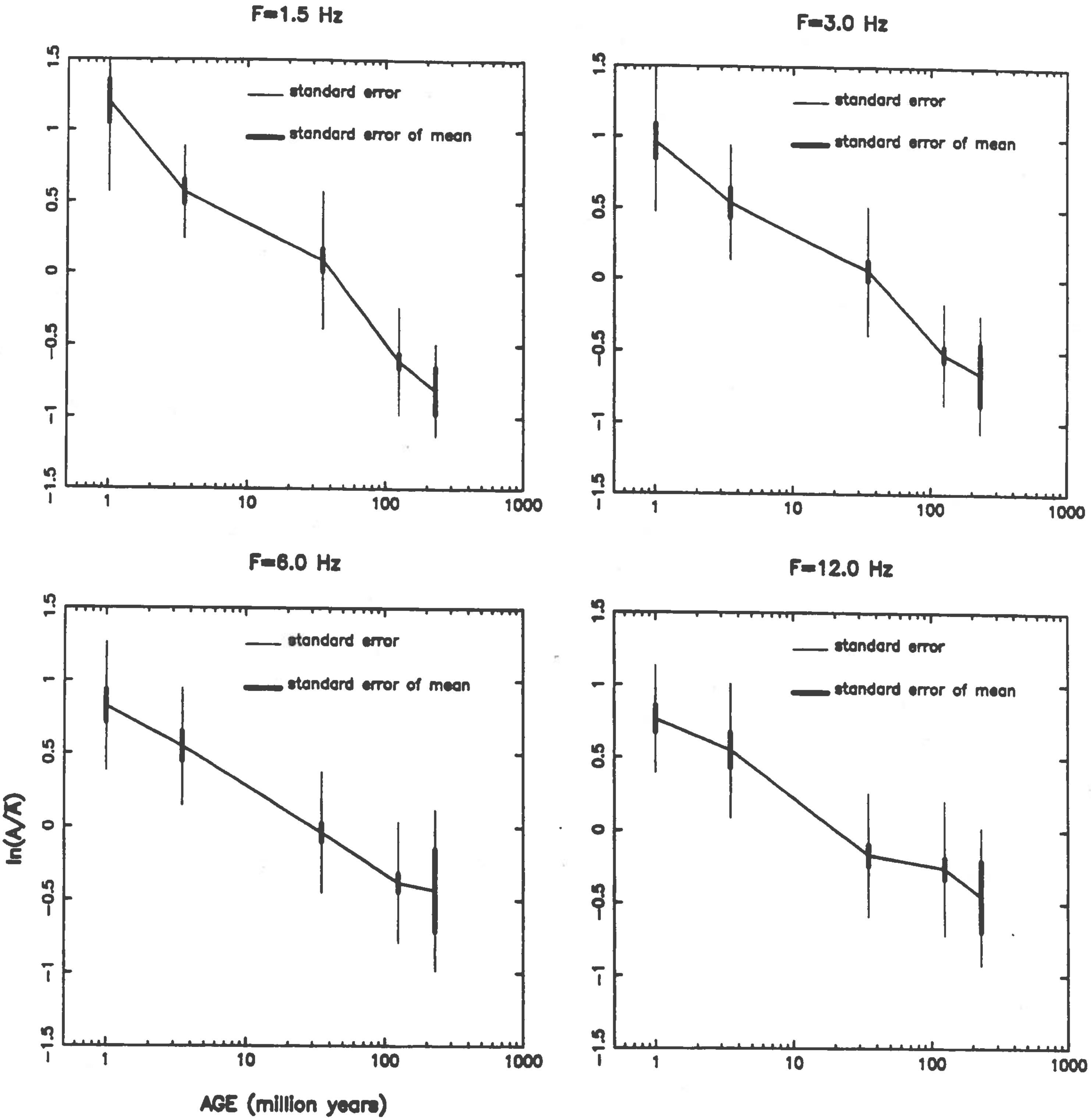
We then extended the same work to the Southern California region and determined site amplification factors at 158 stations of the USGS-CALTECH seismic network. Figure 2 shows the results for Southern California. By comparing Figures 1 and 2, we can see that the general trends for each frequency in these two regions are almost the same, although the standard error for Southern California is larger than that of Central California since the station surficial geology is more complicated in Southern California.

Our results from both Central and Southern California show that younger sites have greater amplification at all frequencies, although the age dependence is stronger for lower frequencies. This is in contrast to the strong motion amplification factor which becomes greater at rock sites than soil sites for frequencies higher than about 5 Hz, suggesting a pervasive non-linear site effect.

Figures 3 and 4 give the spatial distribution of the site amplification factors of Southern California for 1.5 and 12 Hz, respectively. As shown in these two figures, we used seven symbols to indicate seven different site amplification ranges. We found that the Imperial Valley region has very high site amplification, especially for low frequencies.

The relation between weak motion site amplification with geologic age provides a simple way of estimating site effect at a specific site with known surficial geology. The weak motion site amplification results are important for earthquake hazard analysis, seismic zonation, as well as for the comparison of the strong motion site amplification results in understanding the nonlinear behavior of sediment sites.

B-2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F=3.0 Hz
F=6.0 Hz
F=12.0 Hz
standard error
standard error of mean
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AGE (million years)
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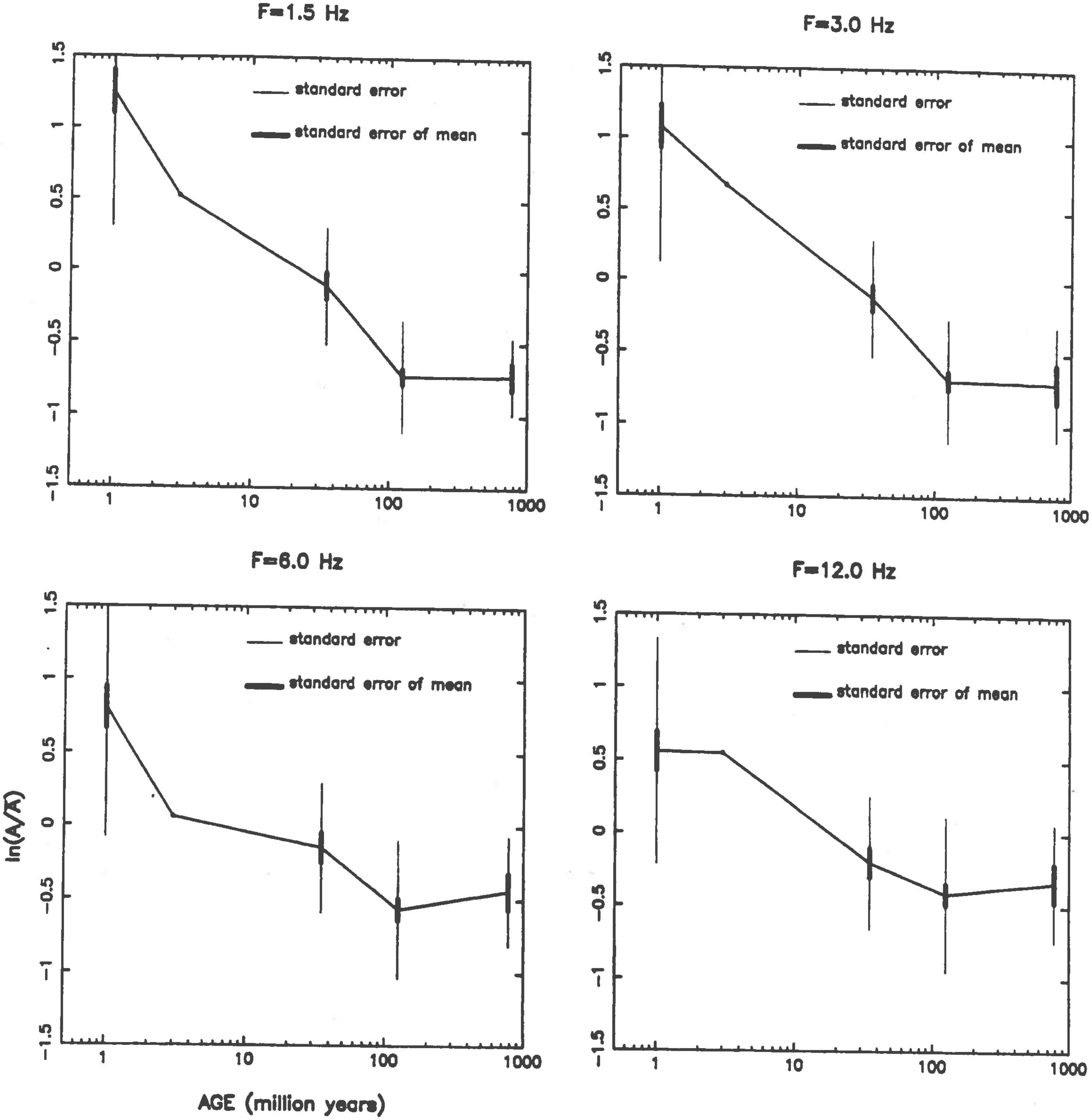
1
0.5
0
−0.5
−1
−1.5
1
10
100
1000

fig. 1


F=1.5 Hz
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F=6.0 Hz
F=12.0 Hz
standard error
standard error of mean
ln(A/Ā)
AGE (million years)
1.5
1
0.5
0
−0.5
−1
−1.5
1
10
100
1000

fig.2

SOUTHERN CALIFORNIA

SITE EFFECT (F=1.5 Hz)

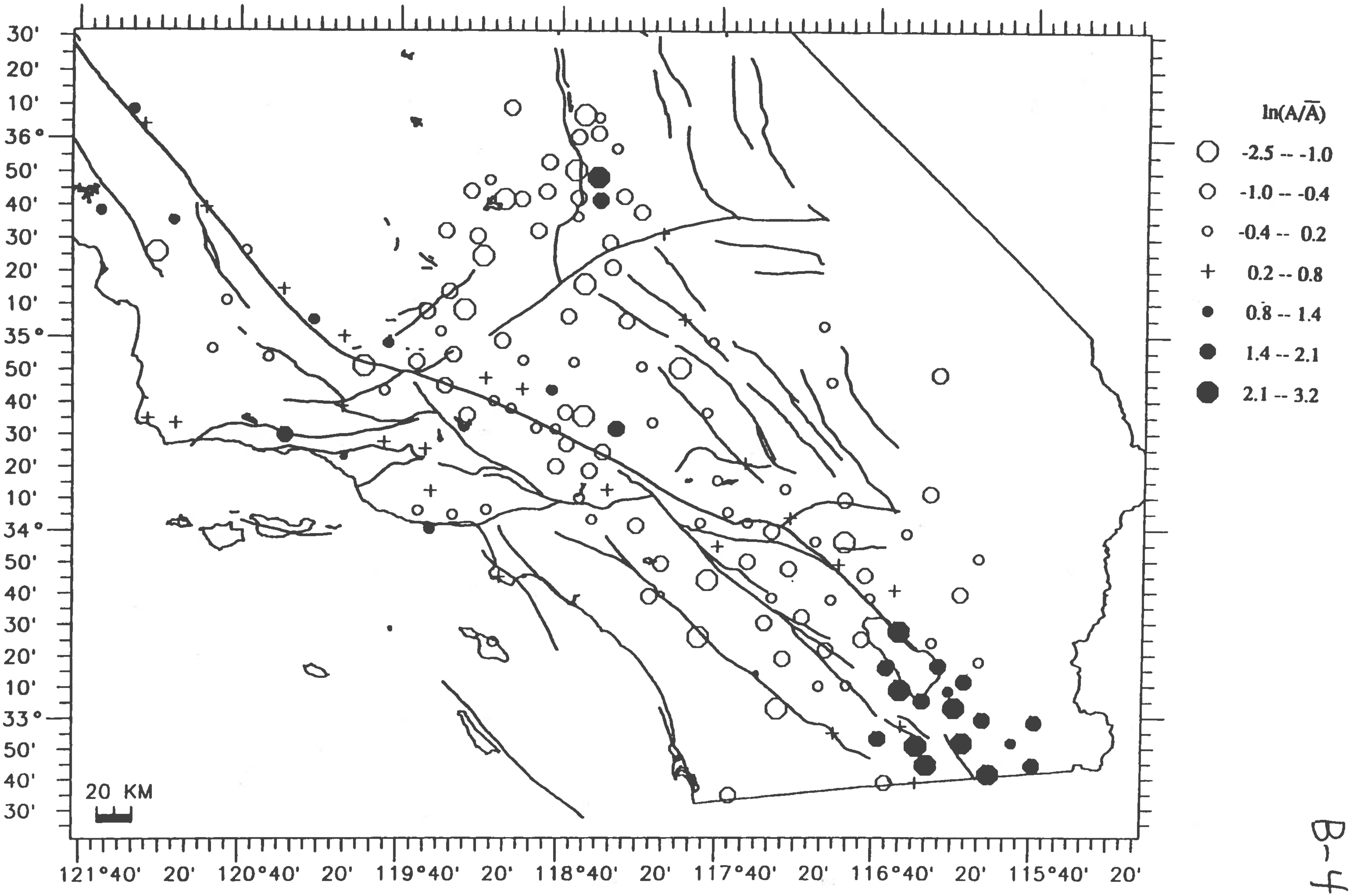


fig.3

B-4

SOUTHERN CALIFORNIA

SITE EFFECT (F=12.0 Hz)

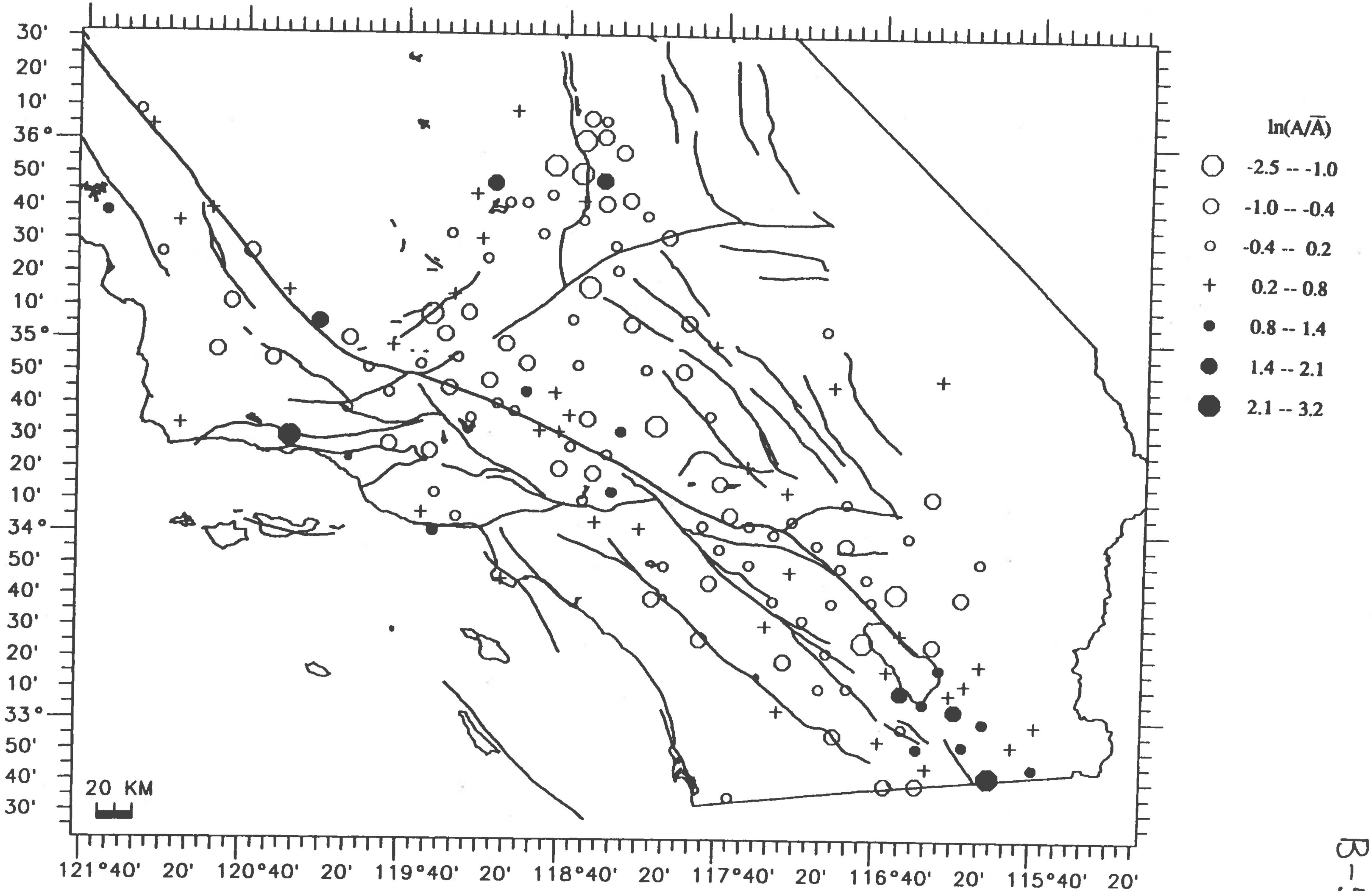


fig.4

B-5

B-6

Status Report:
Characteristics of non-linear soil response: predictions of a time domain code
by John Anderson, Yu Guang, and Raj Siddharthan

The seismological community has become increasingly interested in non-linear soil response as part of the complex site response of strong motion accelerographs. The object of this study is to examine the characteristics of this non-linearity as predicted by a widely used and accepted time-domain code, DESRA. We are not judging the code, but only examining the output from the viewpoint of seismologists who want to understand more thoroughly now non-linear effects will affect strong motion.

Our study is separated into several parts:

1. Impulse response
2. Spectral ratio tests
3. Effect of non-linearity on κ
4. Effect of non-linearity on predictability of strong motion
5. Sensitivity of the above predictions to model parameters

Our most extensive studies have been on the response of a sediment layer to a horizontal impulse in acceleration, incident from below. The input pulse has the shape: $a(t) = C_0 t\exp(-\lambda t)$, with λ selected to have a corner frequency of about 20 Hz. The velocity model represents 20 m of unconsolidated sand overlying rock. The shear velocity and maximum shear stress parameter increase smoothly with depth due to overburden pressure. The layer resonates with a fundamental frequency of about 3 Hz. We have tested the finite-element code DESRA, executing in the linear mode, against predictions of a Haskell program, with almost perfect agreement.

Figure 1 shows the acceleration time series predicted at the surface, $s(t)$ for a several pulses with a range of input peak accelerations. The figure shows $s(t)/a_{max}$ where a_{max} is the peak acceleration of the input. Thus, for linear and small amplitude motion, the peak acceleration at the surface is about 1.5 times the peak acceleration at the base of the model. As the peak acceleration of the input increases, DESRA predicts that the amplification of peak acceleration at the surface decreases due to the non-linearity, until for a pulse with input peak acceleration of 0.5g the peak acceleration at the surface is reduced by a factor of 2. At the same time the initial pulse is broadened by the non-linearity, while the coda of the seismogram continues to oscillate at the fundamental frequency predicted by the linear analysis since the strains are much smaller in this part of the seismogram.

Figure 2 shows the Fourier amplitude spectra of $s(t)/a_{max}$ corresponding to the acceleration time series shown in Figure 1. The spectra show very little effect from the non-linear response at low frequencies, below about 2.5 Hz. Between about 2.5 Hz and 20 Hz, the spectra of the non-linear cases are reduced relative to the linear model. At frequencies above 20 Hz, the non-linear cases actually have more energy in the normalized spectra than the linear predictions. This energy is introduced in this model at the first sign change of the strain and velocity time series, where the stiffness is suddenly increased in the soil deposit according to the hysteretic stress-strain relationship that is assumed for the calculations.

Studies 2 through 5 are still incomplete. With regard to question 3, it appears that non-linear soil response will cause κ to decrease, as might be inferred from the spectra in Figure 2. With regard to question 4, preliminary results have demonstrated that the non-linear response significantly decreases the standard deviation in peak acceleration of an ensemble of random time series, compared to the response of a linear system.

We are now completing our calculations and preparing a manuscript to describe the results obtained to this point. We anticipate that the manuscript might be ready for submission in as little as one month.

B-7

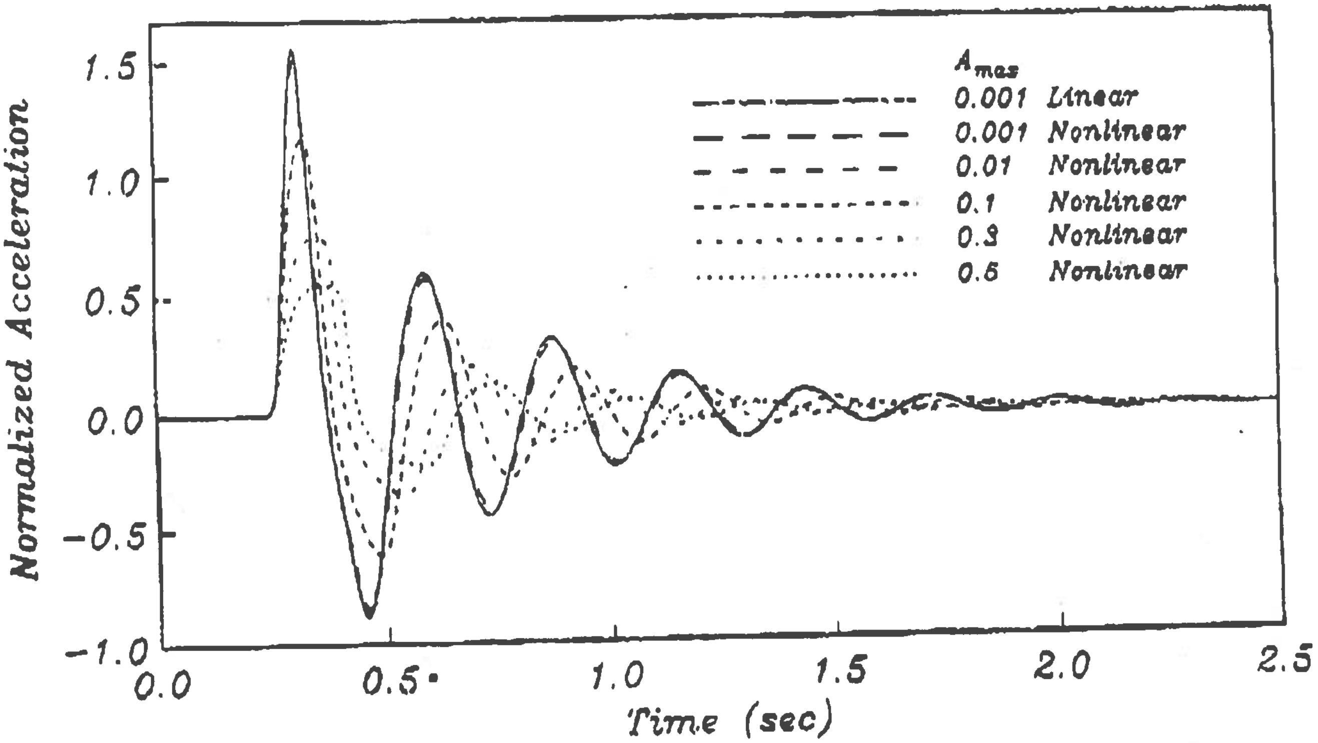

A_{max}
0.001 Linear
0.001 Nonlinear
0.01 Nonlinear
0.1 Nonlinear
0.3 Nonlinear
0.5 Nonlinear
Normalized Acceleration
1.5
1.0
0.5
0.0
−0.5
−1.0
0.0
0.5
1.0
1.5
2.0
2.5
Time (sec)

Figure 4

B-8

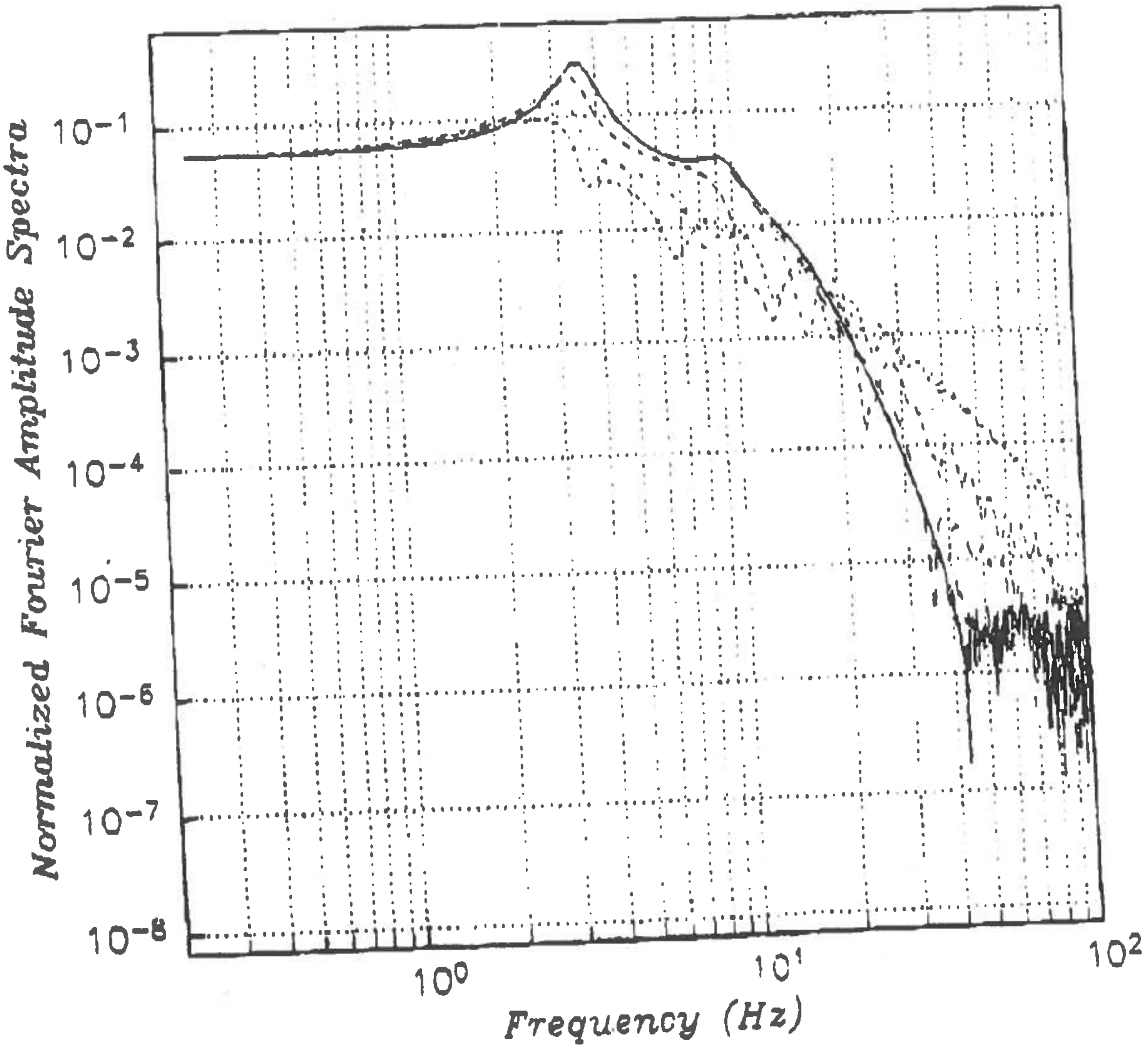

Normalized Fourier Amplitude Spectra
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁰
10¹
10²
Frequency (Hz)

Figure 5

SCEC ANNUAL REPORT 2/90 - 1/91

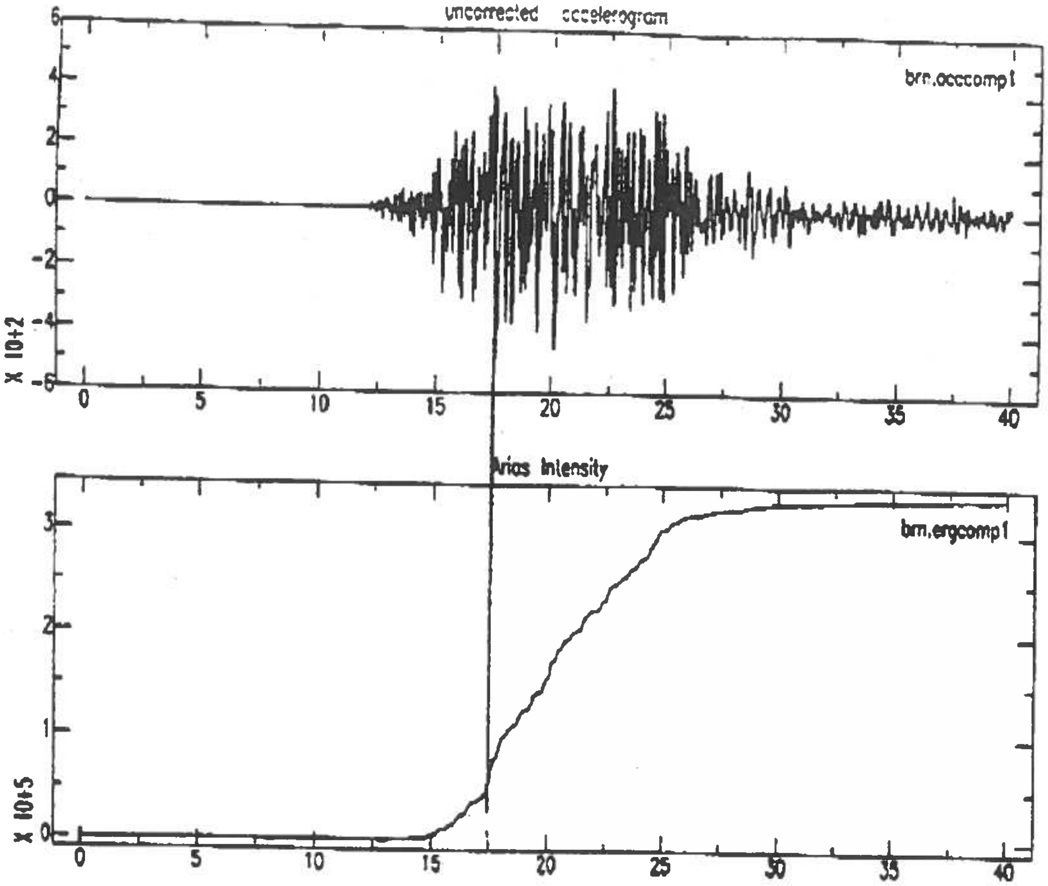
Name of PI Ralph Archuleta

Institution University of California, Santa Barbara

Title of Project Strong Motion Data and Linear Attenuation

This project involves three tasks: initiate a strong motion data base, co-locate portable recorders with accelerographs that have recorded previous large earthquakes, focus on the effect of local site conditions. Rather than reinventing the wheel, we decided that the most efficient means of establishing a database was to connect to the existing NCEER strong-motion database at Lamont-Doherty (STRONGMO). We have also connected to the National Geophysical Data Center at Golden, Co. Using a simple *ftp* command over Internet, we are able to retrieve the existing strong-motion digitized accelerograms. There are problems in the databases related to the assignment of names of earthquakes (e.g. The Southern California earthquake of 1952), magnitudes (Parkfield, M 3.9) and combinations (1940 Imperial Valley Aftershock, M 6.7). However, we have been able to determine that 8 stations have recorded four large earthquakes in southern California; 22 stations have recorded three or more earthquakes, and 76 stations have recorded two or more earthquakes. Because of the efforts of the USGS in Menlo Park (Paul Spudich and Howard Bundock), we have a complete listing of strong-motion stations in southern California. The portable recorders have not been released for field deployments; however, there are obvious sites looking at the list of sites that have previously recorded large earthquakes. In order to examine strong-motion data for possible nonlinear effects we have been looking at two different methods. The first method is a simple use of Arias intensity plotted along with the acceleration time history. The basic idea is that the nonlinearity should strongly dampen the time series by removing high frequencies. Thus the Arias intensity may show a break in slope at the onset of nonlinear response. The second method is based on the concept that nonlinear behavior will lead to a shift in the fundamental frequency at the site. We have been examining various time signal analysis techniques to determine which is best — Fourier amplitude spectra, MUSIC, Prony's method, covariance and auto-regressive. Although each method has its strengths, the auto-regressive method provides well-determined peaks in a smoothed power spectrum. The auto-regressive method can also be related to the current method of simulating accelerogram time histories by random vibration techniques. We have applied the Arias intensity method and the auto-regressive method to data from the 1989 Loma Prieta earthquake. In Figure 1 we compare Arias intensity for a nearby rock site (BRN) with the Arias intensity for an alluvium site (ASH, Agnew State Hospital). Although the Arias intensity differs by a factor of 100, the shape of the Arias curve is nearly identical for the two sites. We are now looking more closely at the data from Yerba Buena Island (Franciscan) and Treasure Island (fill). We have applied the auto-regressive method to rock and alluvium sites. The auto-regressive method definitely shows differences between rock sites and alluvium sites (Figure 2). The alluvium sites have strong peaks around 1.0 Hz and 2.6 Hz while rock sites are generally dominated by a single peak near 2.6 Hz. We will now compare this method with weak motion recorded at the same sites.

B-11


uncorrected accelerogram
brn.acccomp1
6
4
2
0
-2
-4
-6
X 10↑2
0
5
10
15
20
25
30
35
40
Arias Intensity
brn.ergcomp1
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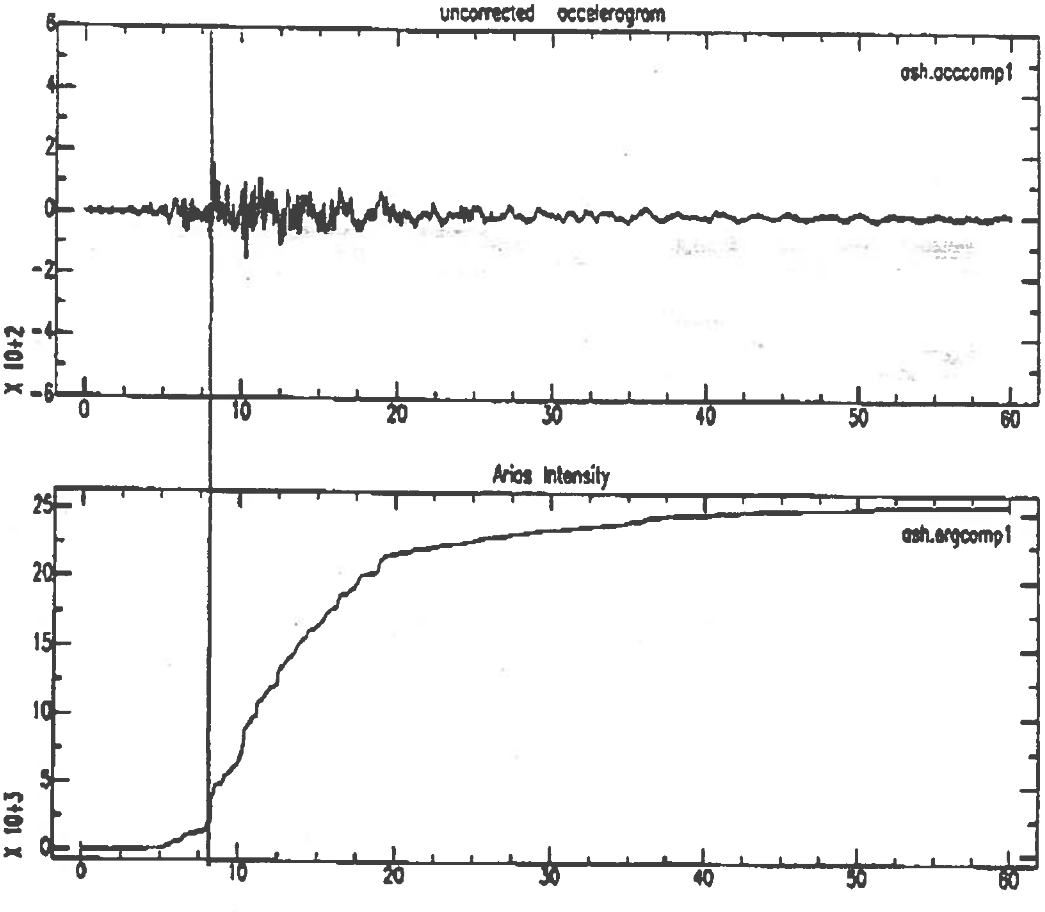
2
1
0
X 10↑5
0
5
10
15
20
25
30
35
40


uncorrected accelerogram
ash.acccomp1
6
4
2
0
-2
-4
-6
X 10↑2
0
10
20
30
40
50
60
Arias Intensity
ash.ergcomp1
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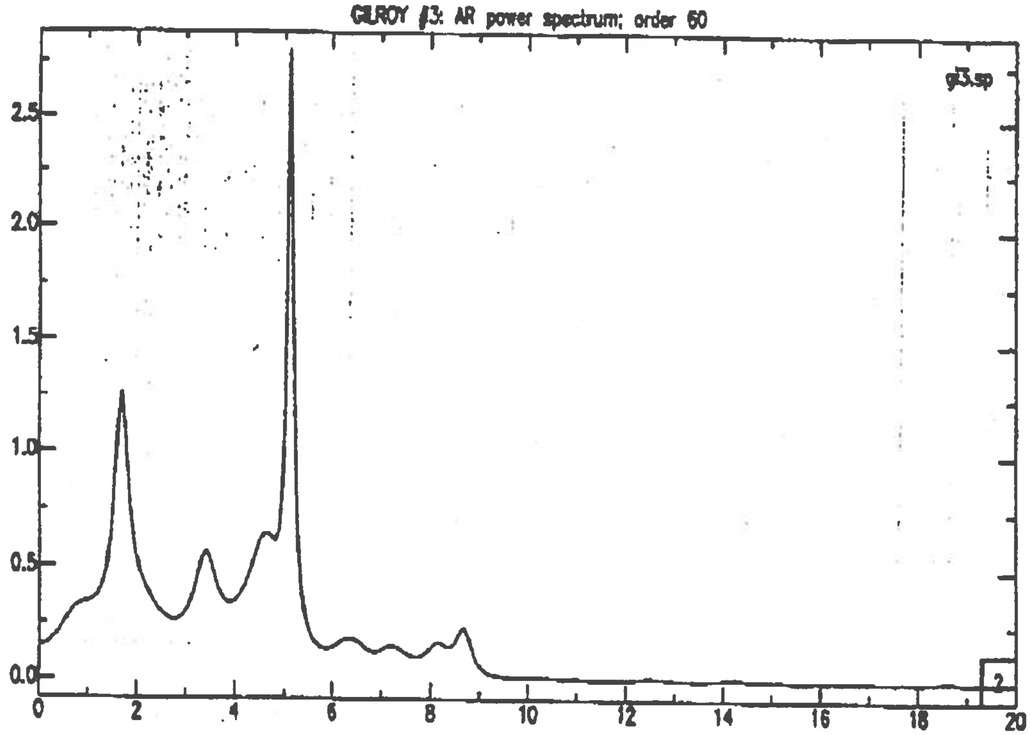
20
15
10
5
0
X 10↑3
0
10
20
30
40
50
60

B-12


GILROY #3: AR power spectrum; order 60
gl3.sp
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1.5
2.0
2.5
0
2
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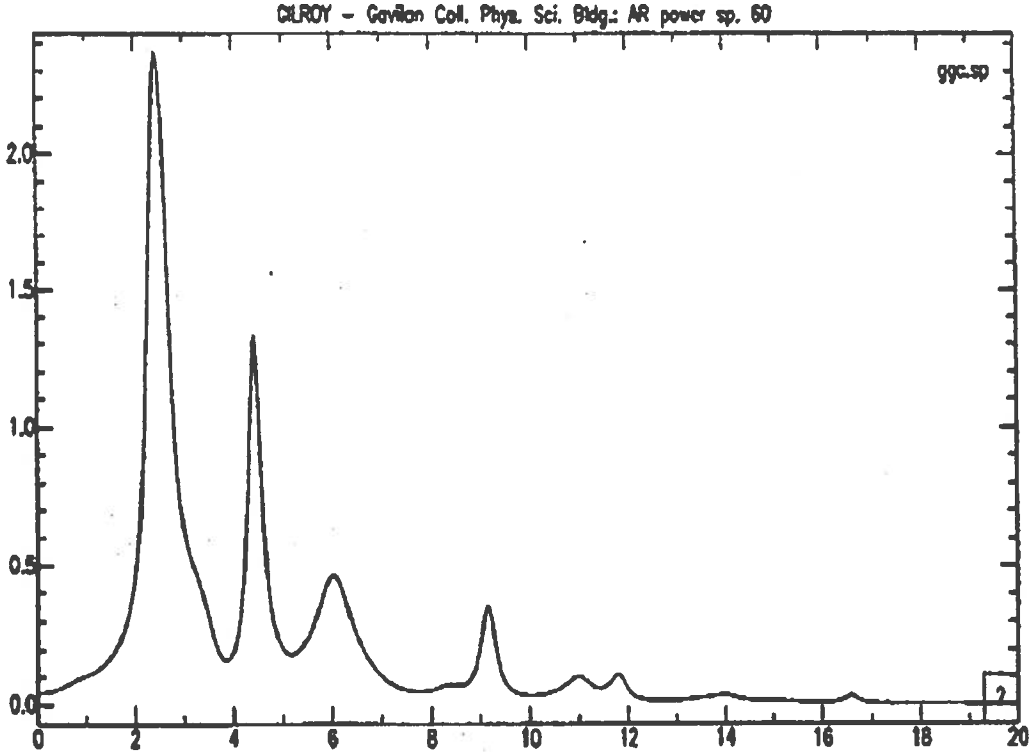
12
14
16
18
20
2


GILROY - Gavilan Coll. Phys. Sci. Bldg.: AR power sp. 60
ggc.sp
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1.0
1.5
2.0
0
2
4
6
8
10
12
14
16
18
20
2

B-13

Strong Motion Prediction for Soil Sites

Status Report
October, 1991

P.I.: Steven M. Day
Institution: San Diego State University

Objective: Among the primary goals of the SCEC are the development, testing, and application of methodologies for the prediction of strong ground motion. An approach which may lead to a practical predictive method is to combine theoretical treatment of the source and wave propagation problem, via Green's function summation, with direct empirical estimation of site-specific amplification factors. In the current project, we have (i) carried out an experiment to test the feasibility of directly measuring the site amplification effect at urban sites, using portable data loggers, and (ii) begun investigating source models for use in the Green's function summation method.

Field experiment. During a two month experiment, we deployed a Kinemetrics SSR1 digital data logger with a short-period, 3-component sensor, in the western part of Mission Valley, in the city of San Diego. The data logger is event-triggered. The site is on the Stardust golf course, located within about 600 meters of Interstate 8. The area immediately around the golf course is quite developed, with an adjacent concentration of major hotels ("Hotel Circle"), and there is a major regional shopping center less than 2 kilometers away. Thus, this deployment provides a reasonable feasibility test for the strategy of directly measuring site responses, with portable, event-triggered instrumentation, for use in strong motion simulations. During the two-month experiment at this site, we encountered substantial problems with noise. Fortunately, however, the most severe noise source at this site, which remains unidentified, was intermittent. During a relatively quite period, we successfully recorded 2 magnitude 2.6 earthquakes, at epicentral distance of approximately 15 km and 150 km, respectively. Both of the 2 recordings had sufficient signal level for use in estimating site amplification in the 2 to 40 Hz. band. Figure 1 shows the north component for the 15 km event, and compares this recording to recordings of the same event obtained on Mesozoic crystalline rock in the eastern part of the city. A strong site effect is evident in the time domain amplitudes and durations, and preliminary Fourier analysis of the S waves indicates a spectral amplification factor (Mission Valley alluvium relative to Mesozoic crysalline sites) exceeding 10 over much of the 2 to 10 Hz band.

Source models. Previous work has shown that a source model which represents an earthquake as an assemblage of subevents can reproduce many of the features of recorded strong ground motion on rock sites. Our extension of this work to incorporate improved representations of soil and alluvial sites is in the code-development stage, and work is continuing.

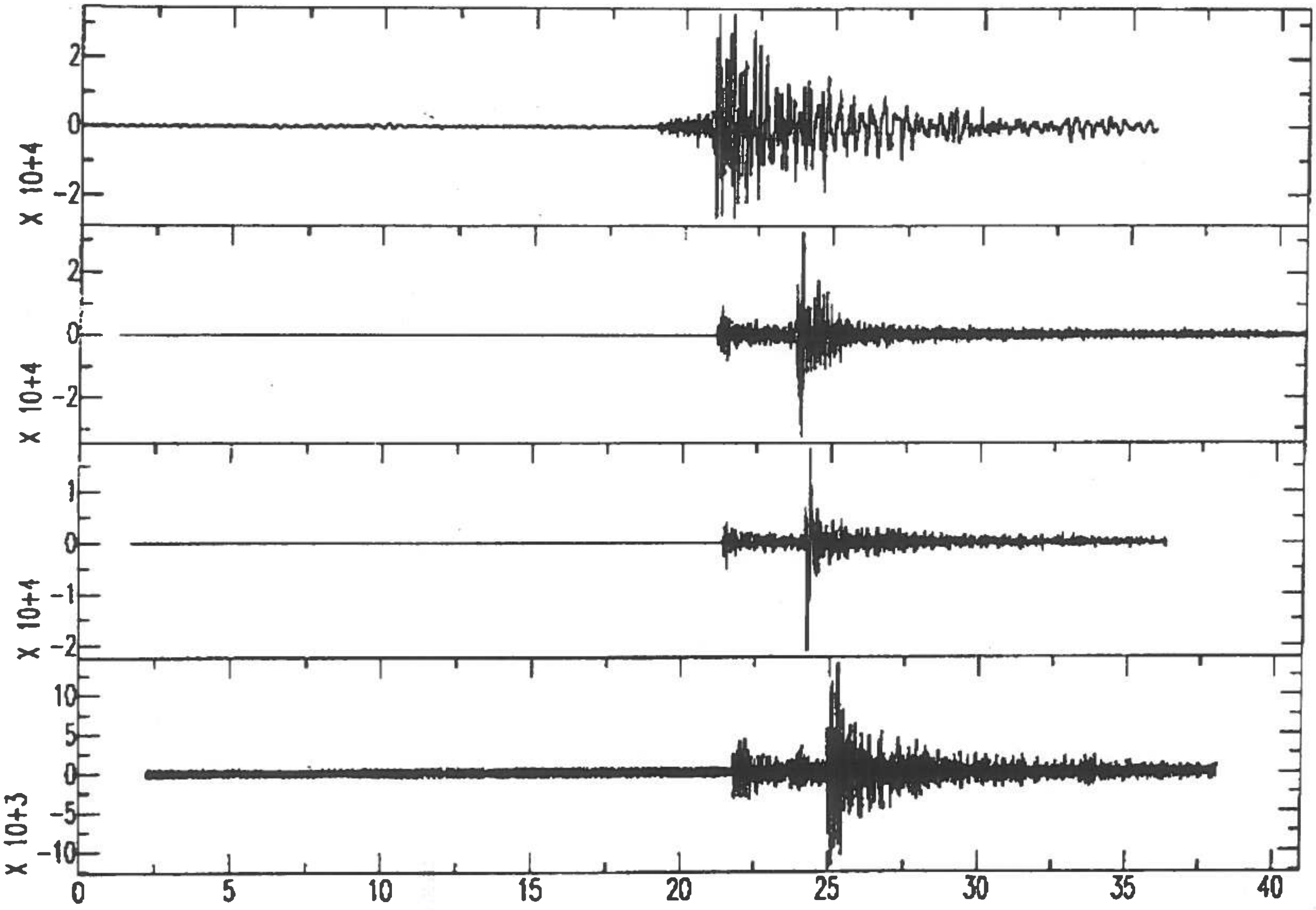


Fig 1. Recorded ground motion (north-south component) for site on Quaternary alluvium in Mission Valley, San Diego, California (top trace), compared with ground motion on Mesozoic crystalline sites in eastern San Diego (lower 3 traces).

Strong Ground Motions in Los Angeles

B-15

Don Helmberger
California Institute of Technology
Pasadena, California 91125

Summary

Objective: A considerable number of events have occurred in the Los Angeles region which have been recorded by conventional SMA strong motion instruments. This data set is not only valuable in assessing the nature of seismic sources but can also be used to constraint the lower complex basin and ridge structures common to the area. Better structures allow more detailed Green's functions which can be used to create a clearer picture of the rupture process (source physics). Secondly, more accurate 2D and 3D velocity models will increase the precision of locations and fault definition. Our major efforts to date has centered on structural constraints provided by one of the well-recorded Whittier aftershocks.

Results: Large variations in seismogram waveforms are generated by the structure of the L.A. Basin. The low seismic velocities of the sediments contrast with the velocities of the solid bedrock, and strong reflections of seismic energy occur at the velocity gradient from sediment to basement rock. The shape of the basin is also significant because the reflected seismic energy may be focussed by the lateral variations in the seismic structure. These effects have been modeled for records of the October 4, 1987 Whittier aftershock from two stations located in the L.A. Basin, both 16 km from the epicenter, see figure 1. A structure of dipping layers with very low shear velocities in the top few layers was adopted to approximate the structure of the basin between the earthquake source (outside the basin) and the receivers. A distinctive feature of the records from the basin receivers is the large amplitude of the first multiple of the horizontal shear wave (a body wave ray which is reflected once off the free surface before reaching the receiver) on the tangential record component, essentially the phase SS. It is difficult to model this multiple at such short range with a flat layered model, so it was taken as a primary constraint of the dipping layered model. By forward modeling, the seismic velocity, depth and dip of the layers were varied to fit the timing between the arrival of the direct SH phase and the first multiple. The dip was found to be a very sensitive parameter for focussing the multiple into a distinct pulse, as seen in the records. The timing of the pulse relative to the direct SH arrival was controlled by the seismic velocity and thickness of the shallowest layers. When the absolute timing of the direct S and direct P arrivals was included as an additional constraint, however, the records could only be fit by increasing the velocity of the deeper layers, just above the earthquake hypocentral depth, to values expected 5 to 10 km deeper in the crust, see the lower panel of figure 1. The best fitting model to date is also displayed at the bottom of figure 1. Figure 2 displays the comparison of synthetics (FD) with observations where many of the details are explained.

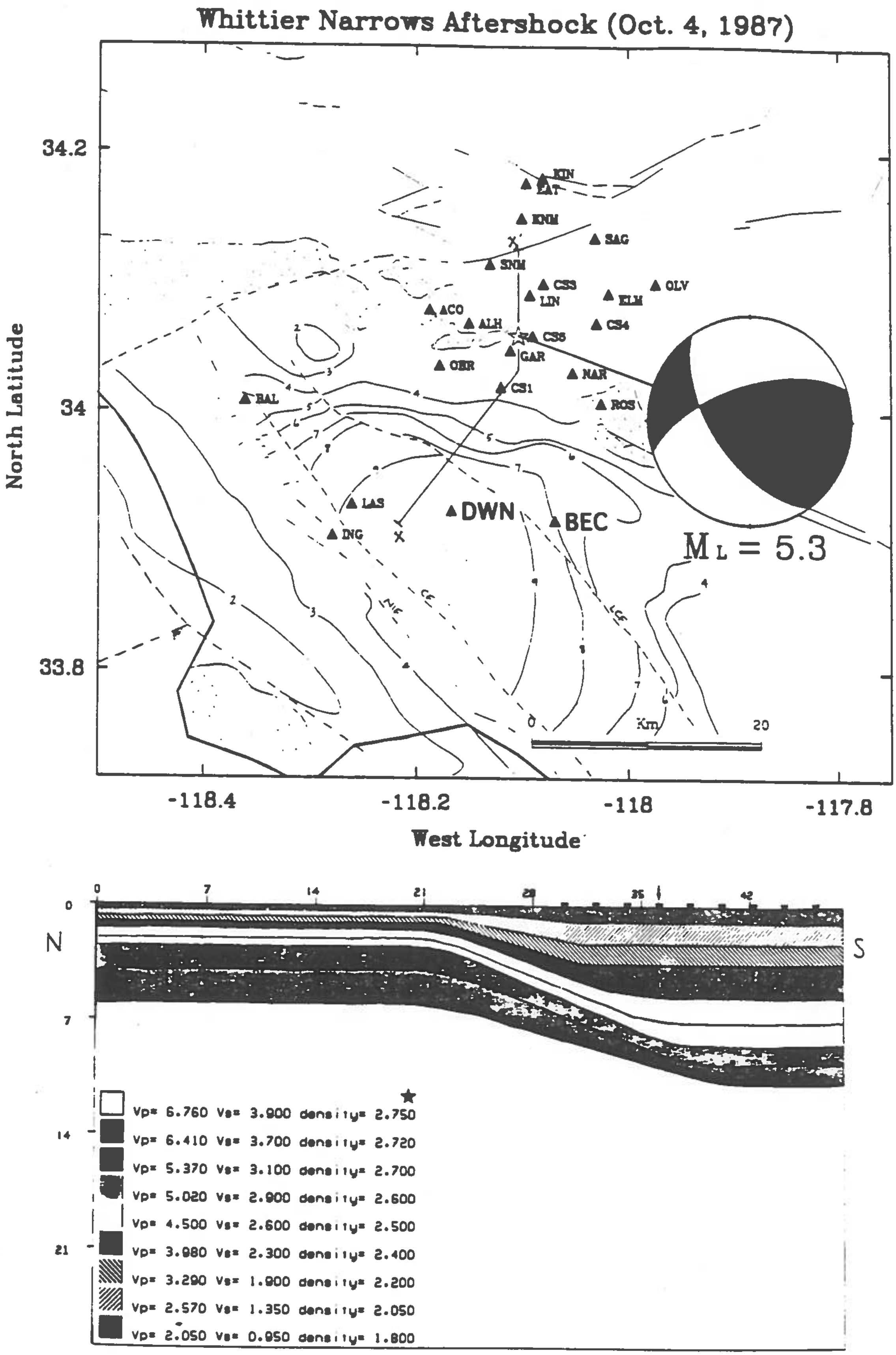


Figure 1. Upper panel displays station locationswhich recorded the magnitude M_L =5.3, Whittier event. Most of the observations are simple except those in the basin. Lower panel displays a 2D model showing the position of the event relative to stations. (after Scrivner & Helmberger, 1991).

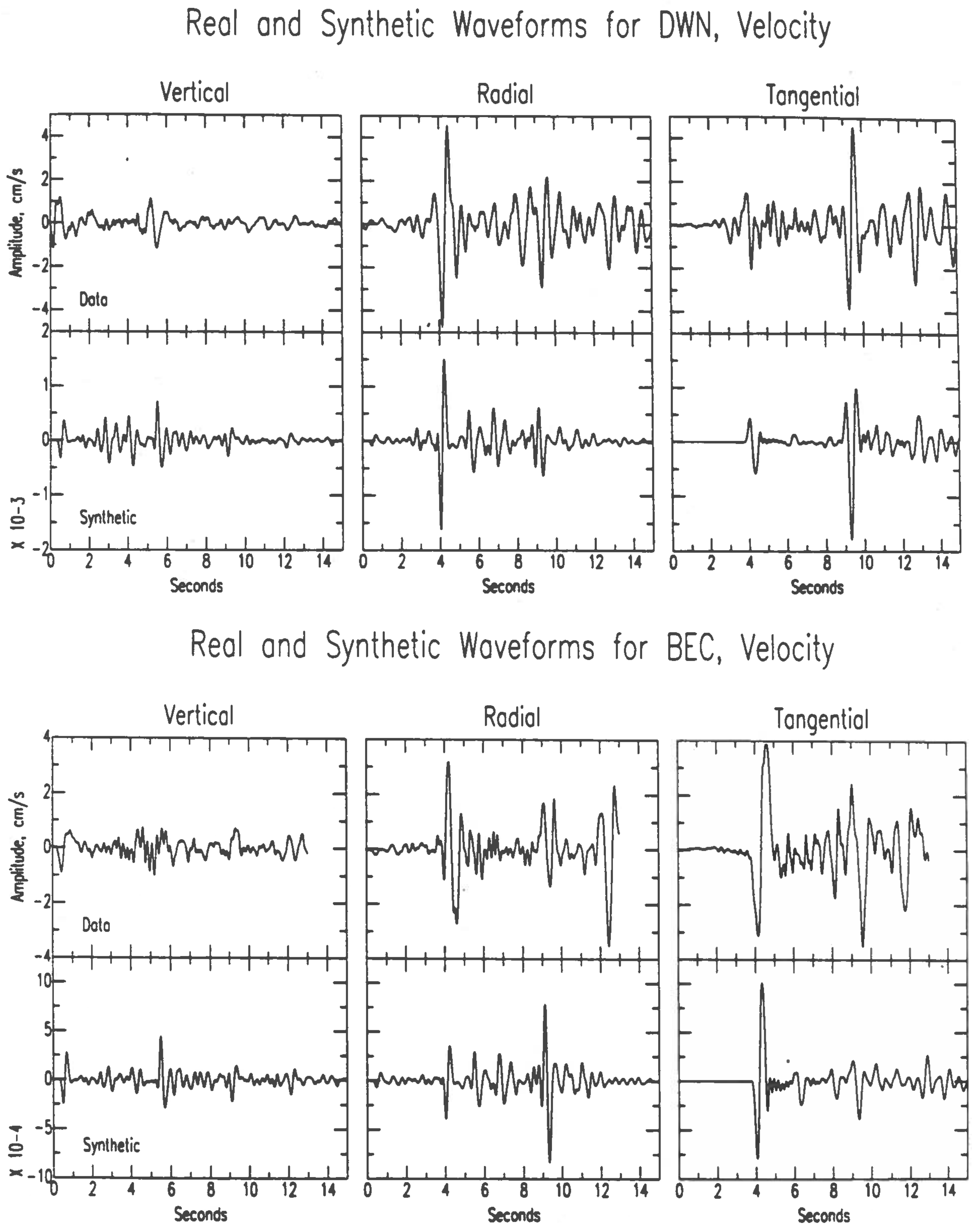


Figure 2. Comparison of observations at DWN and BEC with theoretical predictions from the model given in figure 1.

B-18

PIs	Hiroo Kanamori and Egill Hauksson
Institution	California Institute of Technology
Title of Project	Investigation of Site Response of the Los Angeles Basin Using Portable Broadband Seismographs

A SCEC Project: Goals and Progress Report, 16 Oct. 1991

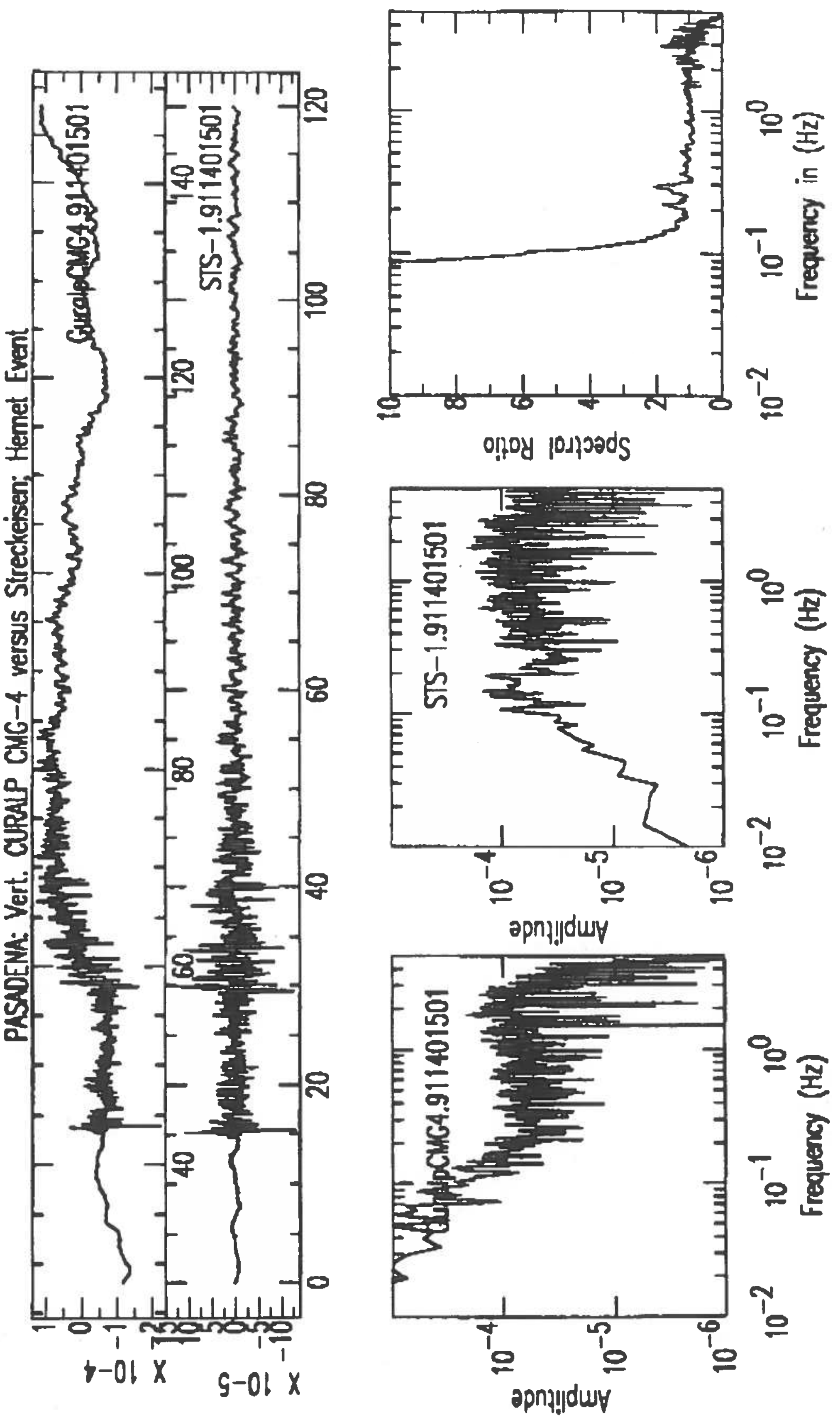
Instrument testing. We deployed two Ref-Tek instruments at the Pasadena Station (PAS) from March to July 1991 to compare and calibrate several different sensors to the Streckeisen STS-1. The sensors being tested were: 1) two 3-component Guralp CMG-4 broad-band seismometers; 2) a 3-component broad-band Ranger; and 3) a single component FBA with velocity output; and 4) 3-component short-period Ranger.

The results of the test showed that the Guralp CMG-4 were not suited for monitoring teleseismic events to obtain the response of the Los Angeles basin. Subsequently, the Guralp CMG-4 seismometers have been returned to the factory and they will be replaced by Guralp CMG-3ESP seismometers. The CMG-3ESP is a much more sensitive instrument, although it will not record strong ground motions on scale. This problem with the sensors has caused some delays in the actual field work initially proposed.

On 27 July 1991 we inspected several potential field sites in the Los Angeles basin with Mr. Rudy Lee of the Los Angeles County, Dept. of Public Works. On 5 August we deployed one of our Ref-Tek instruments with the broad-band Ranger in the the Imperial Yard, near the intersection of the Rio Hondo Flood Control Channel and the Imperial Highway. The broad-band Ranger had performed satisfactorily in the tests done at PAS. So far we have recorded several teleseisms at the Imperial Yard site, although it has proven to be noisy. In the near future we plan to move the instrument to another site, which is the LA County Sheriff station on Firestone Blvd.

Enclosed are two Figures showing seismograms, spectra and spectral ratios for both the CMG-4 and the broad-band Ranger. The spectral ratios show that the ranger performs much better at longer periods than the Guralp.

B-19


PASADENA: Vert. CURALP CMG-4 versus Streckeisen; Hemet Event
X 10-4
X 10-5
CuralpCMG4.911401501
STS-1.911401501
0
20
40
60
80
100
120
140
Amplitude
Spectral Ratio
Frequency (Hz)
Frequency in (Hz)
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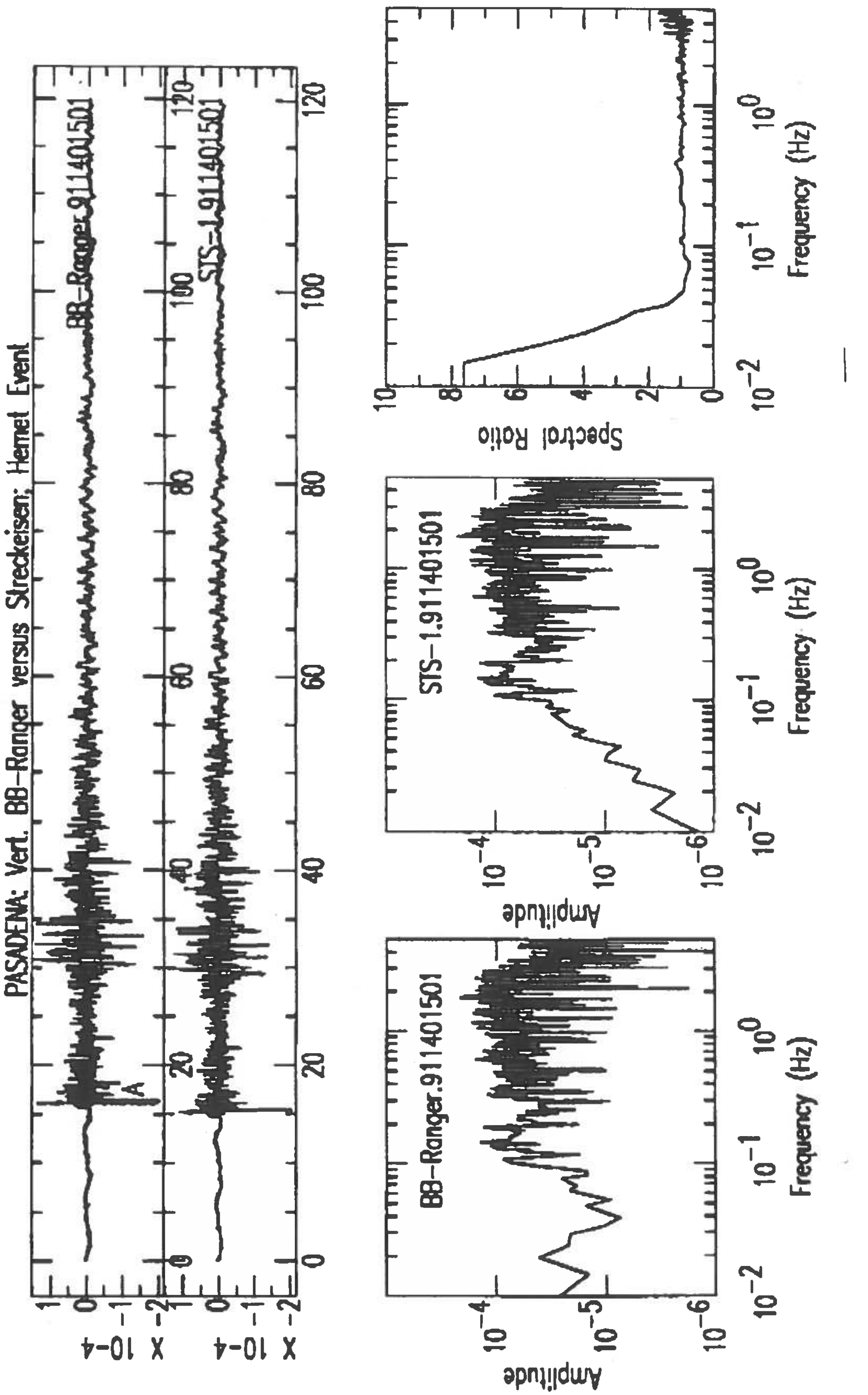
10^{-1}
10^{0}
10^{-4}
10^{-5}
10^{-6}
0
2
4
6
8
10


PASADENA: Vert. BB-Ranger versus Streckeisen; Hemet Event
BB-Ranger.911401501
STS-1.911401501
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Amplitude
BB-Ranger.911401501
STS-1.911401501
10^{-4}
10^{-5}
10^{-6}
10^{-2}
10^{-1}
10^{0}
Frequency (Hz)
Spectral Ratio
0
2
4
6
8
10

Group C: Fault-Zone Geology

Group Leader: Kerry Sieh

Seismic Hazard Potential of the Santa Monica-Hollywood Fault System	Doland and Sieh (Caltech)	C-1
The Role of Active Crustal Shortening and Left-Lateral Faulting along the Central Transverse Ranges, CA	Rubin and Sieh (Caltech)	C-2
ARC/INFO as an Analytical Tool for Problems in Paleoseismicity and Neotectonics	Sieh and Lilje (Caltech)	C-3
Structure versus Earthquakes along the Southern San Jacinto Fault Zone	Seeber and Anders (Columbia)	C-4
Tectonic Geomorphology of the Los Angeles Basin	Keller and Pinter (UCSB)	C-7
Paleoseismic Studies on the Palos Verdes and Whitter faults	Rockwell (San Diego State)	C-8
Marine Terraces and Earthquake Occurrence	Ward (UCSC)	C-9

SEISMIC HAZARD POTENTIAL OF THE SANTA MONICA-HOLLYWOOD FAULT SYSTEM: A PROGRESS REPORT

J. F. Dolan and K. E. Sieh (Seismological Laboratory, Caltech)

Over the past three months we have focused our efforts on a geomorphic study of the WNW-trending Santa Monica-Hollywood Fault system (SM-HFS) in order to elucidate the kinematics, subsurface structural style, and seismic hazard of this portion of the northwestern Los Angeles Basin. Our studies reveal that the NNW-trending Newport-Inglewood Fault (N-IF) separates the SM-HFS into two geomophologically and structurally distinct segments. To the east, linear scarps indicate that recent activity on the Hollywood Fault is concentrated along the topographic mountain front. Active deposition of numerous small alluvial fans at the mountain front, coupled with the absence of any significant fan incision or segmentation, suggests recent, rapid uplift of the Santa Monica mountains in this area. Similarly, the absence of geomorphic or structural evidence for active uplift/tilting south of the mountains in Beverly Hills and West Hollywood indicates that the main active trace of the Hollywood Fault daylights at the mountain front.

In contrast, the active trace of the Santa Monica Fault west of the N-IF forms a series of left-stepping, en echelon scarps 3-4 km south of the mountain front. The presence of several large, deeply dissected and highly segmented old alluvial fans between the active fault and the mountain front suggests relatively little, if any, recent mountain-front uplift. The oldest and most steeply dipping segments of the old fans lie at the mountain front. These surfaces dip only 2-2.5°, indicating that no appreciable tilting of the mountain front has occurred since fan deposition. This absence of active tilting implies that the southern Santa Monica Mountains do not overlie the forelimb of an active, south-verging fault-propagation fold associated with a blind thrust at depth. Rather, most recent contractional deformation is apparently accommodated along the en echelon scarps that cut across downtown Santa Monica.

Consistent up-to-the-north scarps along the entire SMHFS, coupled with growth of the Santa Monica Mountains (evinced by geomorphic features such as the Cahuenga Pass wind gap), clearly indicate that the Santa Monica and Hollywood Faults are, at least in part, south-vergent contractional structures. However, the trend of the Hollywood Fault (about N70E-N85E) is essentially parallel to that of the Raymond Fault along strike to the east, which Jones and others (1990) have shown to be a predominantly left-lateral fault. This observation suggests that the similarly oriented Hollywood Fault may also exhibit a significant left-lateral component of displacement. Our geomorphic analysis failed to reveal any evidence of left-lateral displacement along the Hollywood Fault, however, possibly because active deposition of alluvial fans over most of the fault trace at the mountain front has buried many of these features. Although obvious left-lateral geomorphic indicators (e.g., laterally offset drainages) are similarly absent from the Santa Monica Fault, the left-stepping en echelon pattern of faulting in Santa Monica does suggest an oblique left-lateral component to the Santa Monica Fault. Resolution of the obliquity of displacement on the SMHFS awaits three-dimensional trenching studies.

The active traces of the Santa Monica and Hollywood Faults trend into the N-IF at high angles, and are separated from one another by 1.5-2 km. The N-IF thus appears to locally be acting as a tear fault between the two segments of the SMHFS. Whether or not the N-IF acts as a segment boundary for the SM-HFS during earthquakes remains an important, unanswered question.

C-2

The role of active crustal shortening and left-lateral faulting along the central Transverse Ranges, California

Charlie Rubin and Kerry Sieh, Seismological Laboratory, Caltech, Pasadena, Ca.

Current geologic studies on the Frontal Fault System of the central Transverse Ranges suggest that the Sierra Madre segment is an active tectonic feature and represents a significant seismic hazard along the mountain front. Geologic mapping has concentrated on Quaternary geomorphic features using the 1928 Fairchild aerial photograph collection from Whittier College and USGS topographic maps (6 minute series, 1941) which were published without any cultural information to obscure topographic detail. Although Crook et al. [1987] produced the most detailed map of the the surface trace of the Sierra Madre segment and concluded, that the fault has not been active during Holocene time, our preliminary studies show that the fault has cut Holocene sediments the Holocene, our recent work suggest that the fault has been active during late Quaternary time and represents a significant seismic hazard along the mountain front. Paleoseismic data is sparse for the frontal fault system and the Sierra Madre segment is not designated as active under the Alquist-Priolo Special Studies Zone Act. Between Duarte and La Verne, fresh fault scarps have been identified using the 1928 photographs and verified in the field. Numerous geomorphic criteria, including the presence of hanging valleys, triangular faceted alluvial surfaces and deformed late Holocene alluvial fans, are consistent with an active fault. In addition, three potential excavation sites have been identified along the frontal fault system.

It appears that the Sierra Madre segment is propagating southward of the mountain front between San Antonio and Monrovia Canyons, whereas, to the west, active strands may still be present in crystalline rocks.

C-3

ARC/INFO as an analytical tool for problems in paleoseismology and neotectonics

Dr. Kerry Sieh and Anne Lilje, California Institute of Technology

Progress to date

The initial task was to build a software/hardware system that could be used to be used to manage, analyze and image paleoseismic and neotectonic data sets. There are several considerations binding the implementation of the system. They include the following:

* Handle large and small data sets.
* Ablity to handle data from a wide spectrum of sources. These sources may include the following formats:
  - Hand drawn maps
  - Existing published maps
  - Existing maps and data from computer files including applications programs such as WILDsoft format, AutoCAD formats, TIFF, GIF, EPS,PS, DEM, DLG, and others.
  - System must be able to at least deal with "massaging" the format of files not originally anticipated.

* System must have GIS or GIS-like capabilities
* System must be able to produce both publication quality 8.5" x 11" output and produce larger traditional maps.

After considering many platforms and software packages, it was concluded that we would opt to use ARC/INFO on a SUN SPARCstation II (UNIX) as the core of this system. ARC/INFO in it's present version is a very powerful vector based GIS manufactured by local company (Environment Research Systems Institute, Redlands, California). Our purchase was made through a sitewide licensed agreement between SCEC and ESRI.

After extensive testing, the following hardware was ordered:

1) SPARCstation II with 32 MBytes memory, 19" color graphics accelerated monitor, and a 400 MByte internal hard disk.
2) CALCOMP 9500 series 36"x 48" digitizer.
3) Additional Fujitsu 1.2 GByte external SCSI drive

The final stages of system installation were made the week of Oct 1st. The machine is located on the Caltech campus network and is accessible via internet.

Pilot Project

One of the pilot projects will include synthesizing and databasing a data set collected by Sally McGill along the Garlock Fault. Her project involves the mapping of geologic contacts, observed fault traces, suspected traces and trench localities. Although this database is quite small, the results will point out the utility of bringing in data through several unrelated channels (WILDsoft files, AUTOCAD, visual observations and photogrammetric techniques) and combining them into a finalized database.

C-4

Structure Versus Earthquakes along the Southern San Jacinto Fault Zone

L. Seeber and Mark H. Anders, Lamont -Doherty Geological Observatory

The definition of earthquake sources for hazard assessment in California relays heavily on historic and paleoseismic data on surface ruptures. Equally important, however, are structural and conceptual models concerning the segmentation of faults and the stability of their behavior over many ruptures. The Loma Prieta event in central California focussed our attention on this issue and demonstrated the possibility of multiple characteristic ruptures for the same portion of a fault. The San Jacinto fault zone at the Borrego Badlands offers a unique opportunity to compare long and short-term deformation along this fault zone and to resolve fault interactions leading to distinct superimposed characteristic ruptures. The behavior of the SJFZ at the Borrego Badlands is directly pertinent to seismogenesis from the Anza Gap and may provide a model for the fault zone further north and for similar fault zones elsewhere. The goal of this project is to compare long (Quaternary) and short (historic)term behavior of the SJFZ by using a variety of data including field mapping, gravity , paleomagnetic, and earthquake data.

We have made progress in the analysis of paleomagnetic data from the Ocotillo and upper Borrego formations in the Borrego Badlands. The results establish the magnetostratigraphy of this sequence and constrain the rate of rotation. The results also identify a number of complicating factors, such as fault drag, non-cylindrical folding, compaction, and current magnetization. Our understanding of these issues in the Borrego Badlands improves the resolution of tectonic rotations by paleomagnetic techniques in Plio-Quaternary basins in southern California. A paper concerning these results will soon be ready for submission.

We made progress in the analysis of gravity data along the SJFZ from the Borrego Badlands to the San Felipe basin. This study has resolved diagnostic features of the bedrock surface buried below the sediments. Bedrock morphology reflects northeast structure confirming that cross faults reach into the seismogenic basement. Gravity data has confirmed a cross fault hypothesized on the basis of a set of folds in the sediments and suggest a southeastern extension of the Clark fault as a basement feature into the San Felipe Hills, far beyond its termination at the surface, and may be a hidden source of large earthquakes. Structure and gravity modeling indicate that many of the cross faults dip southeast and have a large normal component. This result may be surprising in view of the pervasive folding of the sediments, but is consistent with the extension and crustal thinning expected in the Salton Trough. Folding in the sediments is interpreted primarily as a by-product of transcurrent faulting in weak sediments with sub-horizontal decoupling layers. On the basis of these and other results we have developed a detachment model of the SJFZ.

The field work planned for spring 1991 has been postponed to this late fall. This work will be carried out by both the principal investigators.

C-5

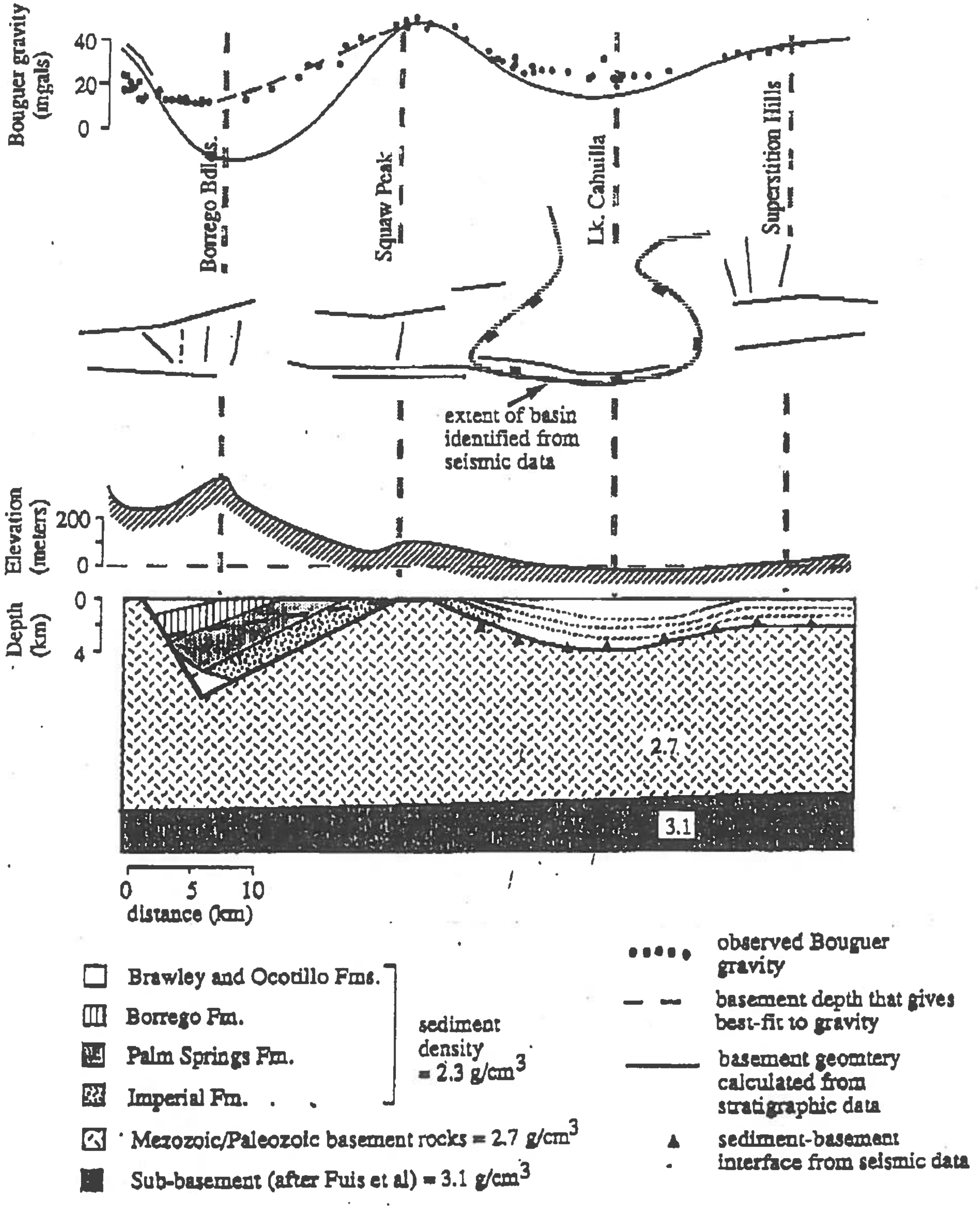

Figure 1. An attempt at modeling gravity along the San Jacinto fault zone, from the Borrego Badlands to the Superstition Hills (Cowey and Seeber, preprint). The results are inconsistent with available structural data. We suspect the problem is with these data and our mapping effort is addressing this inconsistency and other issues brought out by the gravity modeling.

C-6

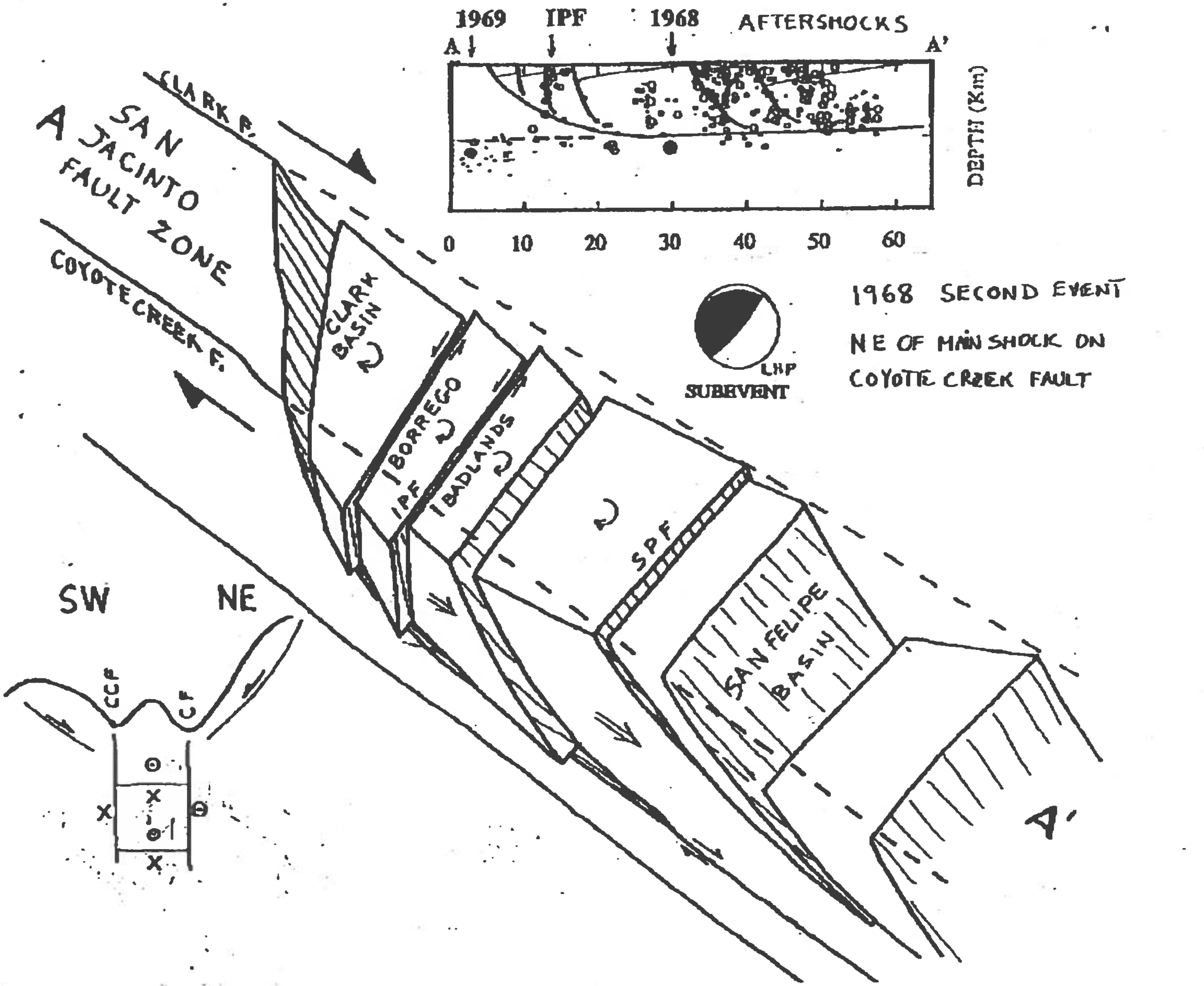

Figure 2. Sketch of a tectonic model for the southern San Jacinto fault zone: an extension/rotation allochthon within two parallel master faults and a detachment (from Cowey and Seeber, preprint). Evidence from gravity and structural data include left-lateral and down-to-the-southeast components on all the cross faults; 20°-30° clockwise rotations in the Borrego Badlands from paleomagnetic data; a substantial portion of the 1968 main shock moment released in a sub-event with a nearly horizontal nodal plane and a slip vector parallel to the fault zone (Petersen et al., JGR in press). In 1968 the allochthon moved southeast relative to the west wall and the floor of the fault zone. A testable prediction of this model is that displacement on the Coyote Creek and Clark faults should increase and decrease to the southeast, respectively.

TECTONIC GEOMORPHOLOGY OF THE LOS ANGELES BASIN: A PROGRESS REPORT

C-7

E.A. Keller and N. Pinter

September, 1991

The objective of this project is to produce tectonic geomorphic maps of the Los Angeles region at a scale of 1:100,000. The maps are intended to show landforms such as fault-bounded mountain blocks, structural hills, mountain fronts, fault-line valleys, prominent marine and river terraces, and fault scarps. The purpose of the mapping is to provide a comprehensive overview of the tectonic geomorphology of the Los Angeles Basin as a whole and to delineate areas where more detailed work is necessary to better understand the tectonic framework and related earthquake hazard.

The philosophical framework we are building our research upon is that surface morphology, given the principles of landscape evolution and an understanding of tectonic and geomorphic processes, reflects the tectonic and seismic history of a region. The study of tectonic geomorphology is based upon the premise that the form of the landscape is a function of process (geomorphic and tectonic); earth materials (broadly defined to include composition, texture, and geologic structure); and time. In other words, tectonic landforms are a function of process and materials integrated through time. This simple relationship provides a way of summarizing levels of tectonic geomorphic inquiry (Gregory, 1978):

- Level 1: Identify of landform elements (basins, ranges, alluvial fans, terraces, fault scarps, etc.) and relating these to tectonic geomorphic processes and earth materials, independent of each other and of time.
- Level 2: Obtain relationships between the geomorphic processes, the materials, and the landforms, independent of time.
- Level 3: Evaluate relationships between the tectonic landforms and earth materials, integrated through time.

Our project is nearing completion of Level 1 at this time, which is the identification of tectonic geomorphic features of the L.A. Basin. We expect that the project in its final form at the end of this year will comprise Level 1 and aspects of Level 2.

In order to take into account the variable scale inherent in tectonic geomorphology, we are mapping and classifying landforms according to a scale-based heirarchy (Crofts, 1981).

Table 1. Landform Heirarchy for Tectonic Geomorphic Mapping (after Crofts, 1981).

Scale	Examples	Imagery
Land region	Los Angeles Basin	1:145k satellite
Land system	small basins, ranges, drainage networks	1:100k topo maps
Feature	alluvial fans, prominent terraces	1:63k air photos
Site	scarps, sag ponds, etc.	1:18k air photos

To date we have completed mapping at the 'region,' 'system,' and 'feature' scales. This mapping has delineated interesting topography related to tectonic processes as interpreted from localized zones of incision and of aggradation, from drainage networks, and from other features. Our next step will be to incorporate all information into a uniform base-map at a scale of 1:100,000. For local sites of particular interest, more detailed maps will be produced at a larger scale. The 1:100,000 scale base-map and accompanying explanatory text and local maps will comprise the final product of this work for the first year.

References Cited

Gregory, K.J., 1978, A physical geography equation: National Geographer, v. 12, p. 137-141.

Crofts, R.S., 1981, Mapping techniques in geomorphology: In A. Gondi (ed.), Geomorphic Techniques, London, George Allen and Unwin, Ch. 2.9, p. 66-75.

C-8

SCEC SUMMARY REPORT - YEAR ONE

P.I.: Dr. Thomas Rockwell
Department of Geological Sciences
San Diego State University
San Diego, CA 92182

Project Title: Paleoseismic studies on the Palos Verdes and Whittier faults

Results: Trenching of the Palos Verdes fault at Harbor Park is requiring unanticipated permit aquisitions. Consequently, actual trenching of the fault does not appear possible before the end of the rainy season in 1992. Therefore, I focused on a related fault, the Rose Canyon-Newport-Inglewood fault zone, that also has a poorly constrained slip rate and that poses a substantial seismic hazard to most of coastal southern California. Most of the 1991 summer was spent trenching the Rose Canyon strand of the zone. The northern Elsinore-Whittier fault is presently under study and trenching will continue through the end of the first project year on this fault. Both studies complement previous or ongoing studies supported by the NEHRP.

Trenching of the Rose Canyon fault (complementing NEHRP support to Scott Lindvall) demonstrated a minimum of 8.7 m of dextral slip in less than 8100 years B.P. (dendrochronologically corrected), yielding a minimum slip rate of 1.1 mm/yr for most of the Holocene. Analysis of the geomorphology of the fault zone suggests a best estimate of 1.6±0.5 mm/yr for the entire fault zone in San Diego. The fault parallels the coast to the northwest and is continuous (as a zone) with the Newport-Inglewood fault that bisects the greater western Los Angeles metropolitan area. Consequently, this study also provides a minimum dextral slip rate for the fault that generated the 1933 M6.3 Long Beach earthquake.

Paleoseismic studies along the northern Elsinore-Whittier fault are underway as of September, 1991. 3-D trenching of the fault this fall will further constrain the slip rate for this important fault zone and, with continued study, may provide information on the timing and size of previous slip events.

C-9

Progress Report, October 1991: Marine Terraces and Earthquake Occurrence.

SCEC Working Groups: C (Fault Zone Geology) and E (Geodesy).

Steven Ward, Institute of Tectonics, University of California, Santa Cruz

Synthetic Seismicity. Most of my SCEC related research in the past seven months has been directed toward demonstrating how synthetic seismicity calculations, based on the concept of fault segmentation and incorporating the physics of faulting through static dislocation theory, can improve earthquake recurrence statistics and hone the probabilities of hazard. I have made substantial progress in this project as documented in two *Journal of Geophysical Research* papers, one accepted and one submitted. Compared to forecasts constructed from a hand full of earthquake recurrence intervals, forecasts constructed from synthetic seismicity (see Figure 1) are more robust in that they embody regional seismicity information over several units of magnitude, they can extrapolate seismicity to higher magnitudes than have actually been observed, and they are formulated from a catalog which can be extended as long as needed to be statistically significant. Synthetic seismicity models can also be used to judge the stability of common rate estimates and the appropriateness of idealizations to the earthquake cycle. I find that estimates of fault slip rate are unbiased regardless of sampling duration while, on the other hand, estimates of earthquake recurrence time are strongly biased. Recurrence intervals estimated from seismicity samples less than about ten times the actual recurrence interval will almost certainly be too short. For the Middle America Trench, it would take about 200 and 400 years of monitoring to constrain slip and recurrence rates to ±10%. Increasing gap time generally increases conditional probability of earthquake occurrence, but the effect is weak. For the MAT, the spread parameters of the best fitting lognormal or Weibull distributions (≈ 0.75) are much larger than the 0.21 intrinsic spread proposed in the Nishenko-Buland hypothesis (See Figure 2). Stress interaction between fault segments disrupts time or slip predictability and causes earthquake recurrence to be far more aperiodic than has been suggested. With the arrival of Dr. Barrientos, a SCEC visiting researcher, in January 1992, and continued funding, we intend to apply this technique to the San Andreas fault with an eye toward reviewing the conditional probabilities proposed by the Working Group on California Earthquake Prediction.

Ward, S. N., A Synthetic Seismicity Model for the Middle America Trench, *Jour. Geophys. Res.* (in press), 1991a.

Ward, S. N., An Application of Synthetic Seismicity Calculations in Earthquake Statistics: The Middle American Trench, *Jour. Geophys. Res.*, (submitted), 1991b.

Marine Terraces. Space geodesy tells us that ≈8 mm/y of roughly North-South motion is being accommodated between Palos Verdes and the base of the Transverse Ranges. The goal of this work is to employ geological and geomorphological data to isolate the fraction of this motion on some of the faults closest to the coast. I have recently met with Dr. Ken Lajoie of the USGS Menlo Park and have reviewed his substantial data set on the heights and ages of marine terraces around Palos Verdes and Huntington Mesa and other geological information on the dome structures further north and inland. I don't foresee too much difficulty in translating the terrace data, through dislocation modeling, into slip rates for the Palos Verdes, and possibly the Newport Inglewood, faults. Figure 3 presents preliminary results which suggest repeat times on the Palos Verdes fault of 150 and 900 years for magnitude 6 and 6.5 earthquakes respectively. Dr. Lajoie and I have discussed other data sets (i.e. Ventura anticline) and envision continuing the project into 1992. The arrival of Dr. Valensise, a SCEC visiting researcher, in January 1992, should increase the pace on this aspect of the project.

C-10

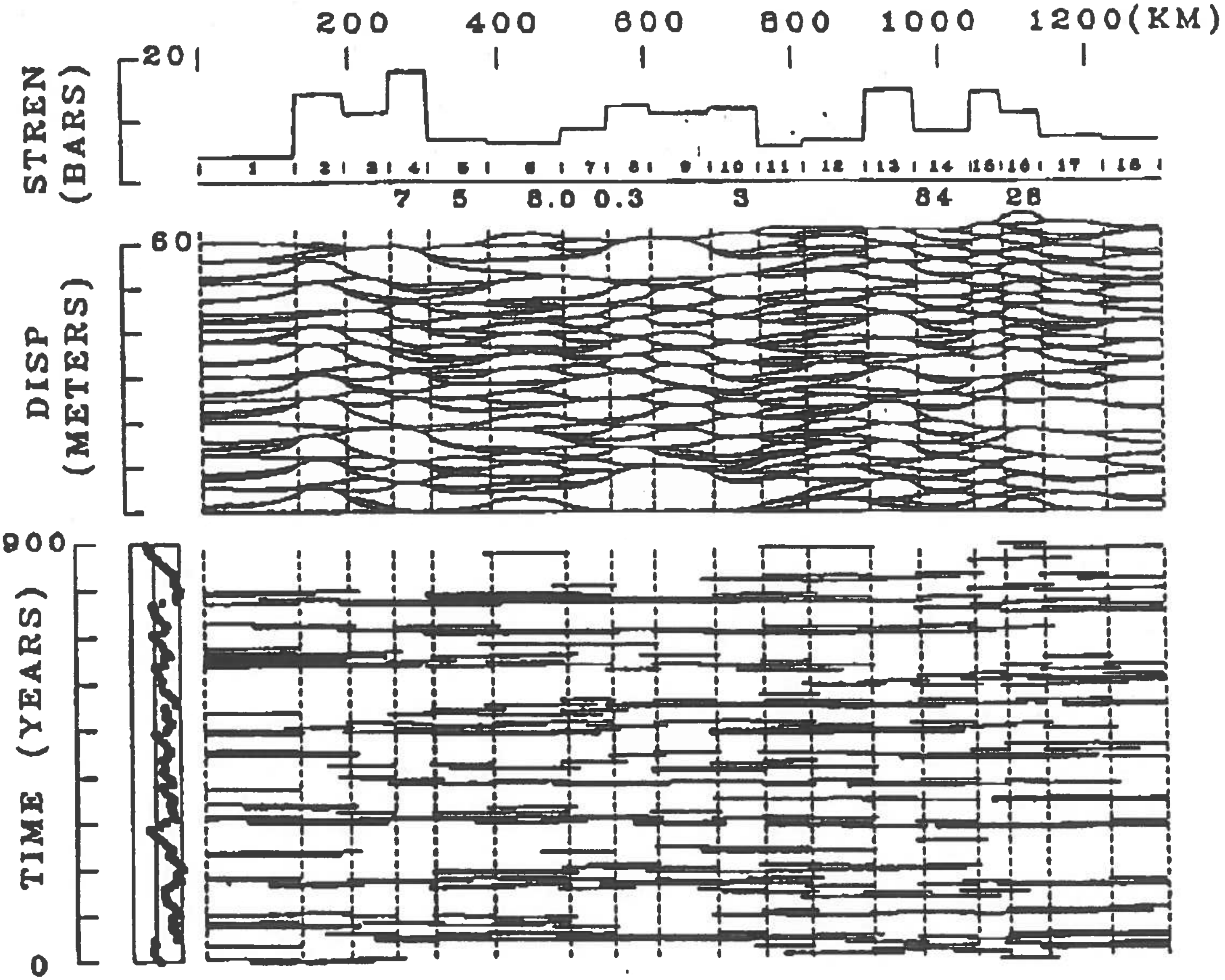

Fig. 1. Generic synthetic seismicity calculation for the Middle America Trench from *Ward* (1991a). *Top.* The sawtooth curve shows the distribution of segment lengths and strengths comprising this realization of the plate boundary. *Middle.* Accumulation of tectonic displacement along the 1300 km of fault strike. Each pillow represents the slip from an individual earthquake within the initial 900 years of a 4000 year run. *Bottom.* Space-time distribution of seismicity. Each horizontal line segment maps a $M \geq 7$ earthquake. Bold segments are $M \geq 8$ events. The statistics of recurrence of various size earthquakes within each segment is the prime concern of this work.

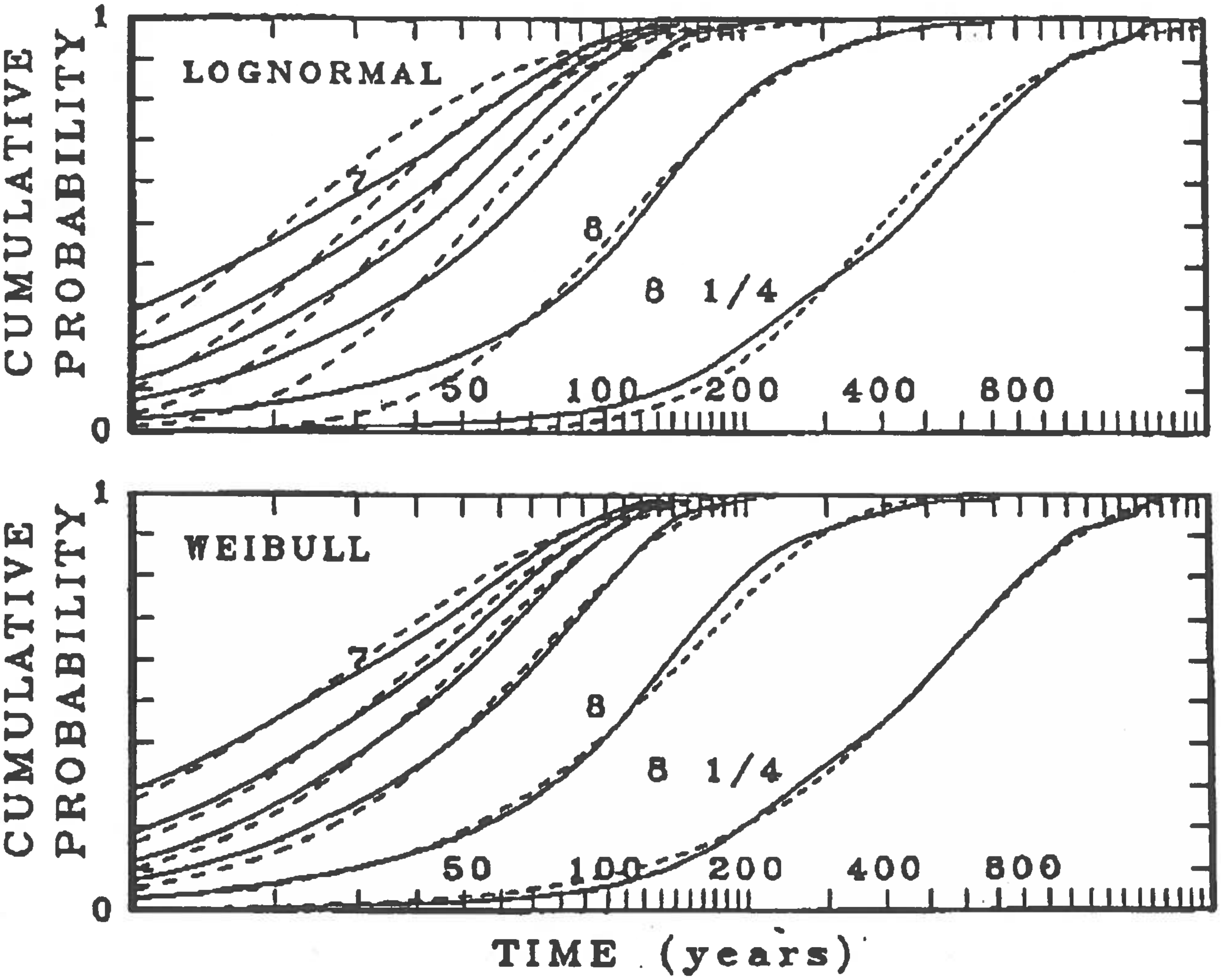

Fig. 2. Best fits of lognormal (*top*) and Weibull (*bottom*) distributions to the model MAT statistics. Each distribution was constrained to have the appropriate mean recurrence time. The remaining free parameter was searched for best fit at each M_o. The Weibull distribution better represents the statistics of recurrence than does a lognormal distribution. The spread parameters of the distributions are not constant, but generally decrease with magnitude. In all cases they are substantially larger than the intrinsic spread value of 0.21 proposed by *Nishenko* and *Buland* (1987). The larger spread reflects a higher degree of aperiodicity in the recurrence of major quakes.

C-12

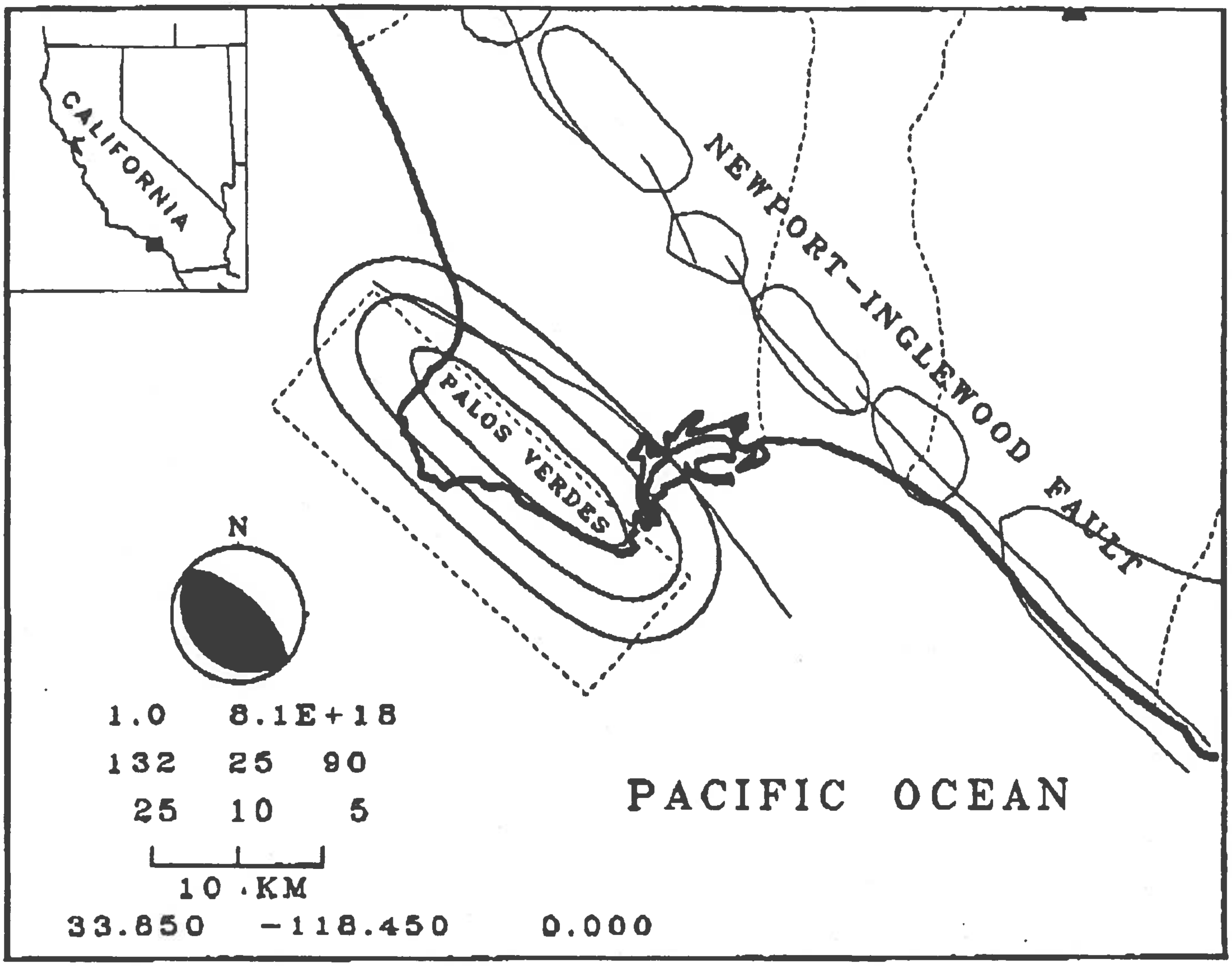

Fig. 3. Map of the Palos Verdes region of southern California showing major drainages (*wiggly dashed lines*) and dome structures associated with the Palos Verdes and Newport-Inglewood fault systems. Marine terrace data at San Pedro indicate that the Palos Verdes peninsula has been uplifting at a rate of about 0.21 m/ky over the last 2 million years. If this uplift is the result of repeated thrust earthquakes on the Palos Verdes fault, it is possible to estimate its geometry and long-term slip rate. The contours over the peninsula represent the uplift rate in 0.1 m/ky intervals which would be generated from repeated slip on a thrust striking 132°, dipping 25°, and coming to within five kilometers of the surface. The fault (*dashed rectangle*) is 25 km long, 10 km wide, and slips at 1 mm/y. For a fault of this size and slip rate, magnitude 6.0 and 6.5 earthquakes could recur every 150 and 900 years respectively.

Group D: Subsurface Imaging of Seismogenic Zones

Group Leader: Rob Clayton

D-1

THE OFFSHORE NEWPORT-INGLEWOOD FAULT ZONE AND ADJACENT COMPRESSIONAL STRUCTURES: DANA PT.-OCEANSIDE

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J.K. Crouch & Assoc's, Inc.
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Santa Barbara, CA 93101

Investigations

Multichannel seismic-reflection profiles across the southern California margin between Dana Pt. and Oceanside illustrate structural details of the offshore Newport-Inglewood Fault Zone (NIFZ) and reveal a fold-and-thrust belt seaward and parallel to the NIFZ (Figures 1&2). Key horizons on a number of these profiles have been converted to depth and an evaluation of shortening and convergence rate normal to the NIFZ has been assessed. Also, a structure contour depth map has been constructed and this map along with selected depth sections are being drafted for publication. Offshore wells, bottom samples, and geologic relationships were used to constrain the timing of fault normal compression to about 3.6 m.y. to Recent. The seismic-reflection profiles also provide important clues as to the initial (early Miocene) development of the NIFZ and the inner southern California margin. Features that are being analyzed, in terms of the early history of the NIFZ, include rifting, detachment, and uplift along the margin.

Results

Across portions of the offshore NIFZ a marked asymmetry in deformation is recognized. East of the zone, continuous beds of middle Miocene and younger strata dip seaward about 10 to 15 degrees but are otherwise relatively undeformed (not folded). As much as 7 km west of the NIFZ, however, these same strata are compressed into tight asymmetric folds underlain by thrust or reverse faults. Using the line length method for retrodeforming these strata, the convergence rate normal to the NIFZ is estimated to be on the order of 0.6-0.7 mm/yr and the overall shortening west of the NIFZ is estimated to be about 0.4 km over a maximum distance of 7 km. The reverse and thrust faults and overlying folded strata west of the NIFZ appear to cut or affect strata at the seafloor. However, over the past 10 years the area in which these structures occur has generally been devoid of earthquakes of magnitude 2.0 and greater. It is concluded that these faults and folded strata may be deforming aseismically because they are riding on an uplifted detachment surface. The detachment surface itself probably formed during a period of early-late Miocene rotation and extension within the region west of the NIFZ.

D-2

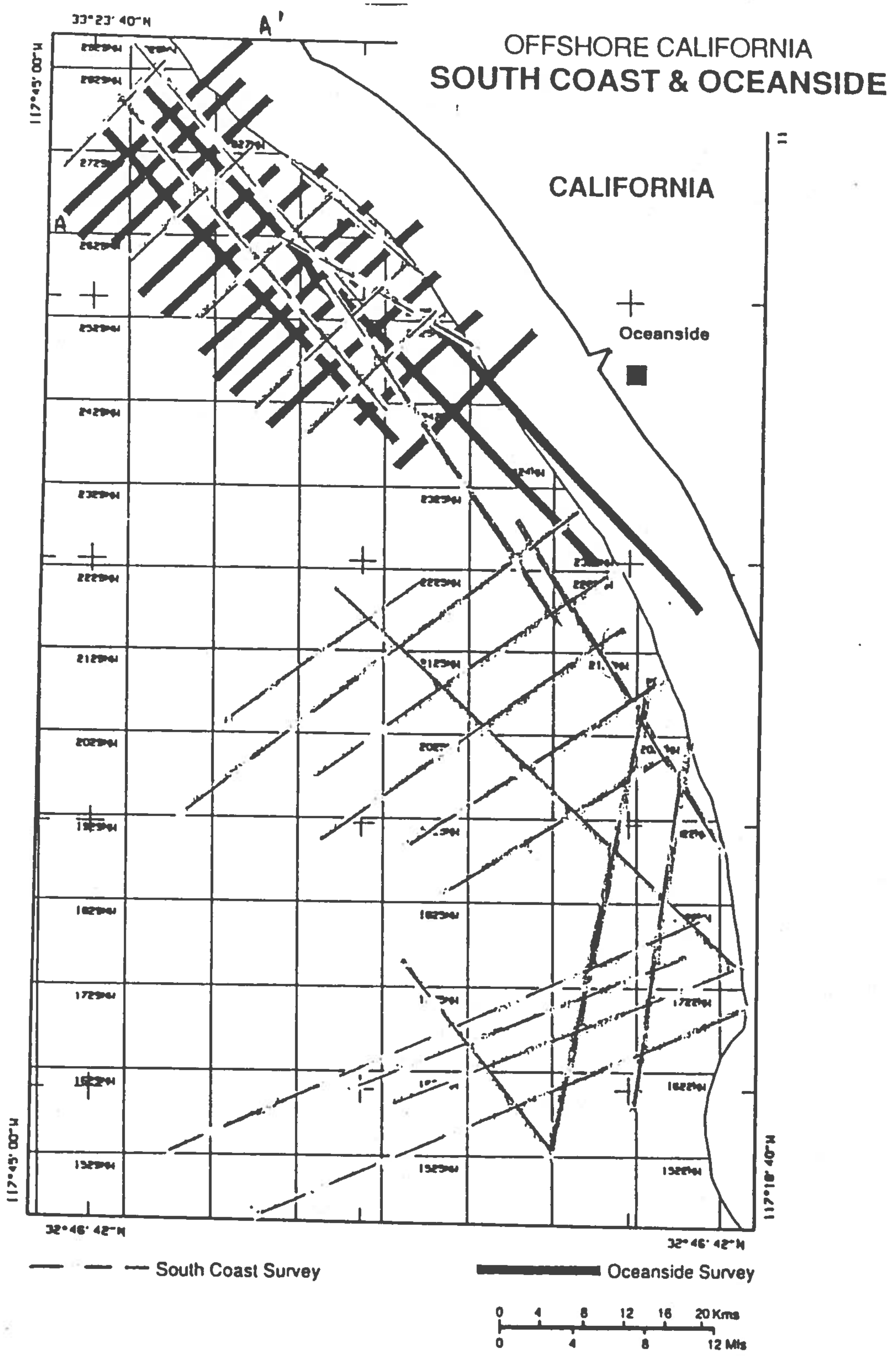


Figure 1 --- Trackline map of offshore seismic-reflection data. Location of figure 2 indicated by A - A'.

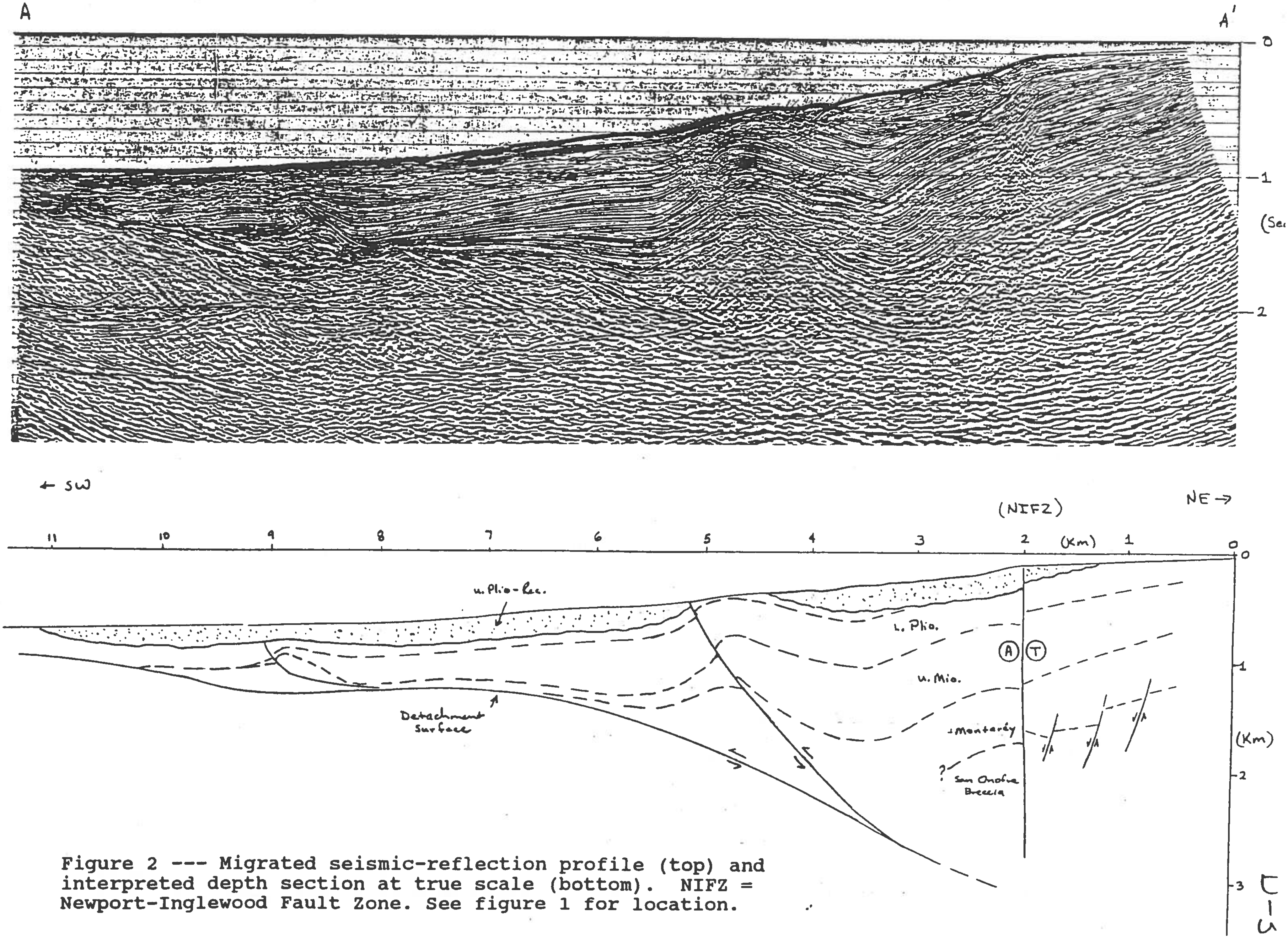


Figure 2 --- Migrated seismic-reflection profile (top) and interpreted depth section at true scale (bottom). NIFZ = Newport-Inglewood Fault Zone. See figure 1 for location.

Regional Map-View and Cross-Sectional Determination of Fault Geometry and Slip for Blind Thrust Faults in Populated Areas of Southern California

Principal Investigator: John Suppe
Institution: Princeton University

Data Acquisition and Research:

Our focus to date has been data acquisition in key areas for the purpose of imaging major seismogenic fault segments and for determining long-term slip rates. We have recently obtained permission to use of an extensive proprietary seismic reflection survey in the Los Angeles Basin, from which we will construct and distribute maps of axial surfaces. Mapping axial surfaces or kink bands generated by bends in underlying faults is the fastest and least interpretive way of determining fault slip and major fault segmentation for hidden thrust, normal, and oblique-slip faults. This method of map view analysis will highlight and constrain key areas through which to construct balanced cross-sections. In addition, constraints on fault slip and subsurface fault geometry will provide a basis for integrating diverse research projects of the earthquake center, including geodesy, cross-section construction, crustal kinematic, and dynamic modeling. Axial surface maps that we have constructed through the Santa Barbara Channel, California, have constrained slip and the subsurface geometry of major blind thrust faults. Oblique-slip on one deep seated thrust, which ramps upward at a fault bend from > 16km, produces the kink band (A - A'), (Fig. 1). The width of the kink band measured in the direction of motion (S) is the fault slip. The axial surface map also highlights tear faults which may terminate or offset the kink band and underlying fault ramp. These offsets may act to segment faults and limit the rupture area of a single event. Moreover, the magnitude of potential past and future ruptures may be predicted from the area of unsegmented faults using empirical relationships between earthquake magnitude and rupture area; in this case $M_s = 7.1$ is predicted. Syntectonic, or growth sedimentation atop these kink bands quantitatively record rates of fault slip. Sediments deposited earlier in the slip history of the underlying fault record wider kink band widths than do sediments deposited later. These kink bands which narrow upward into younger section, or growth triangles, have been recognized in seismic and well section in the Santa Barbara Channel and Los Angeles Basin (Fig. 2). If the ages of selected growth horizons are known by independent methods, rates of fault slip can be calculated. Using this method, we have determined that the deep fault beneath the Santa Barbara Channel slips at a rate of 1.7 mm/year. Further, these slip rates can be combined with estimates of the magnitude of fault rupture to determine recurrence intervals of potential earthquakes; in the case of Fig. 1 the interval is about 1200 years. We are also in the process of collecting significant amounts of subsurface electric well log data from the Los Angeles Basin, including logs from the Newport-Inglewood trend. Expanded sedimentary sections reported in these wells are used to long-term slip rates.

D-5

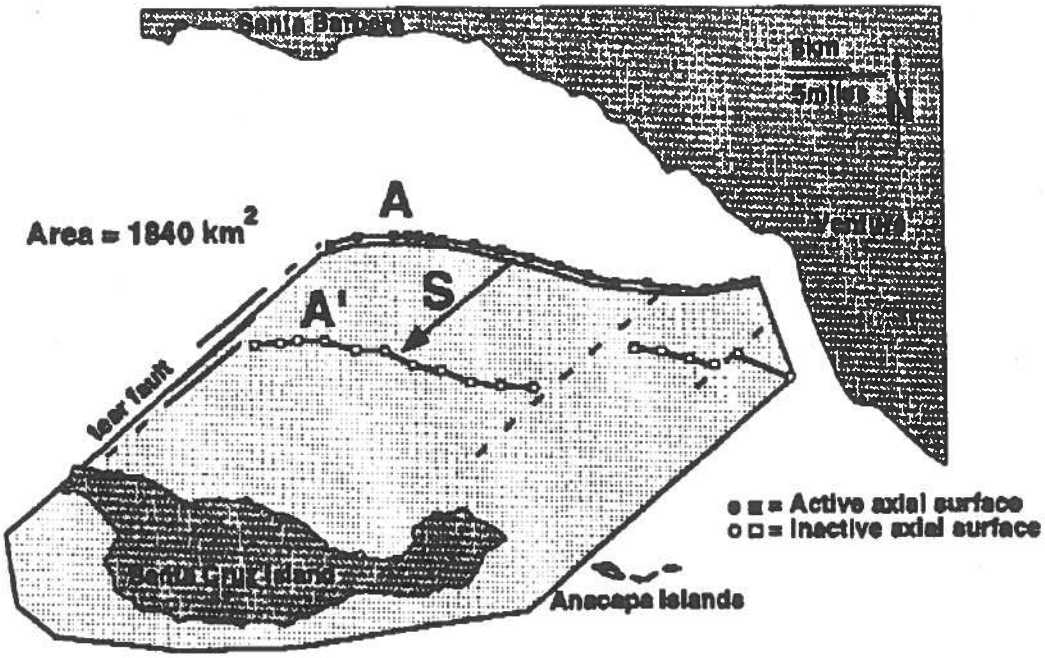


Figure 1: A map of axial surfaces in the eastern Santa Barbara Channel, CA. The axial surfaces bound a kink band formed during Pliocene and Quaternary motion on an underlying oblique, right-lateral blind thrust (S = total slip). Continuity of the active axial surface (A) suggests that the underlying fault ramp, which approaches the seabottom south of Santa Cruz Island, is continuous over an area of at least 1840 square km.

D-6

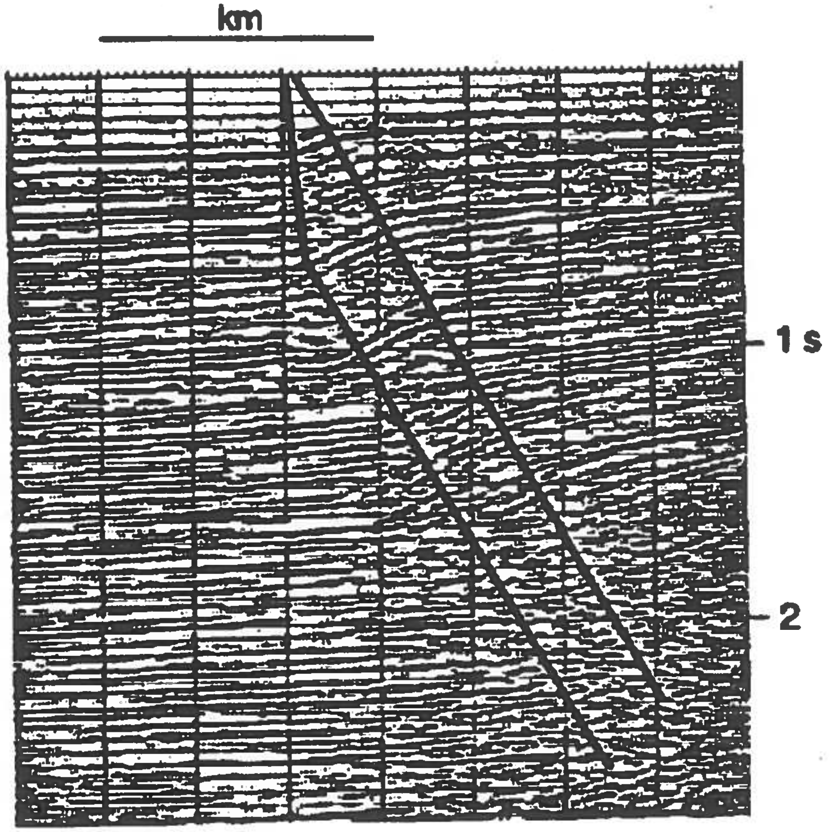


Fig. 2A. Example of active growth kink-band structure above blind thrust on seismic section from central LA Basin seismic survey. Slip on the fault began at the time of deposition of the layer at 0.7 s on the left, the layer for which the kink-band begins to narrow upward.

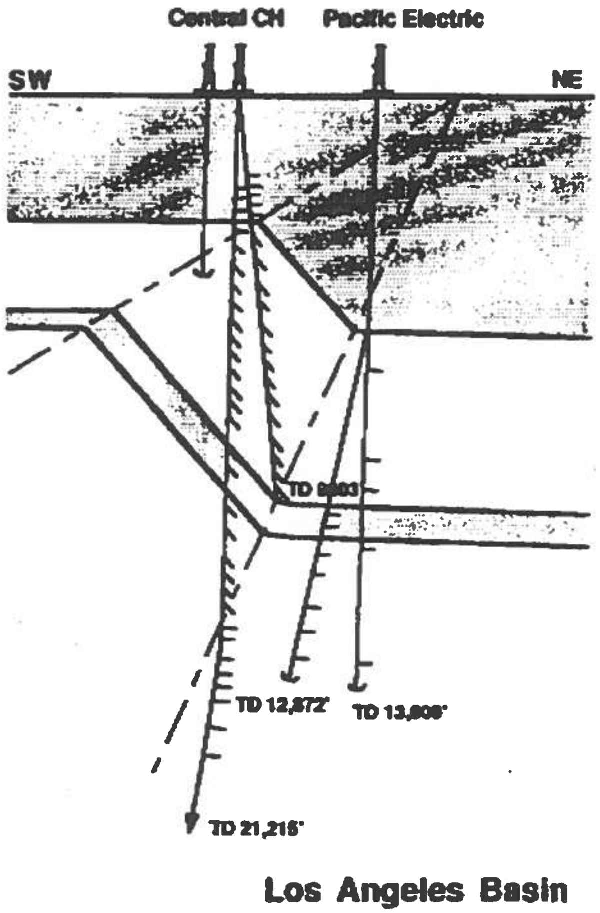


Fig. 2B. Well section through active growth structure above blind thrust fault in central LA Basin. Preliminary estimates of the earthquake magnitude for this hidden fault based on axial-surface mapping similar to Fig. 1 is in excess of Ms = 7. The seismic survey will allow accurate assessment of this magnitude.

D-7

SUBSURFACE GEOLOGY OF NORTHERN LOS ANGELES FOLD-THRUST BELT

The base of Pleistocene gravels (base of San Pedro?) locally is conformable with the underlying Pico Formation and locally overlies Pico and older rocks with angular unconformity (Figure 1). Structure contours (Figure 2) define a broad east-west arch (Wilshire arch) along Wilshire and Olympic Boulevards east of La Cienega Boulevard and, farther west, crossing I-405 at Wilshire Boulevard. The arch has a broad left step at the northern projection of the Newport-Inglewood fault west of La Cienega Boulevard. The Los Angeles basin syncline ends westward at this projection of the fault. Farther north, the base of the Pleistocene dips gently northward toward the Hollywood fault of Dibblee (1991) near La Cienega Boulevard. These data suggest that the Hollywood fault is not a near-surface feature of a blind thrust, although the Wilshire arch may be related to a blind thrust. A structural cross section shows another major unconformity at the Pliocene-Miocene contact. Our impression is that the active anticlinorium postulated based on the Whittier Narrows earthquake is a more complex structure than previously assumed.

RESIDUAL GRAVITY MODELING OF BALANCED CROSS SECTIONS

We have "gravity-truthed" a cross section constructed by Namson and Davis that extends from Santa Monica Bay NNW across the Santa Monica Mountains at I-405, across the San Fernando basin and Merrick syncline, to the San Gabriel fault. This exercise is not meant to be a criticism of Namson and Davis, but rather an example of checking a balanced cross section with an independent data set and how that might affect a structural interpretation.

The isostatic residual gravity is from A. Griscom (written communication, 1991; see Jachens and Griscom, 1985 and Griscom and Sauer, 1991). The isostatic residual removes the effects of topography and the Moho so that the residual, high-frequency gravity anomaly is the gravitational expression of near-surface structure. The section is digitized and modeled using the GM-SYS modeling program. Densities for the various rock units are from McCulloh (1960) and Corbato (1963). The greatest discrepancy between the gravity and structure is over the Merrick syncline, which is resolved by decreasing sediment thickness and by making the Lopez fault low dipping to the north. Furthermore, there is less sediment in the San Fernando Valley than modeled. Both these corrections affect total bed length of the section. Gravity modeling of the published Davis et al. (1989) section requires such minor changes that shortening estimates are not affected.

REFS. Corbato, C., 1963, U. Cal. Pubs. Geol. Scil 46:1-32
Dibblee, T., 1991, Dibblee Foundation Maps DF 30 and 31
Davis, T., et. al., 1989, JGR 94:9644-9664
Griscom, A. and Sauer, P., 1991, AAPG Bull. 75:366
Jachens, R. and Griscom, A., 1985, in Hinze, W., ed., The utility of regional gravity and magnetic anomaly maps: Soc. Expl. Geoph.
McCulloh, T., 1960, USGS Prof. Paper 400B, B320-326

Bob Yeats
OSU

D-8

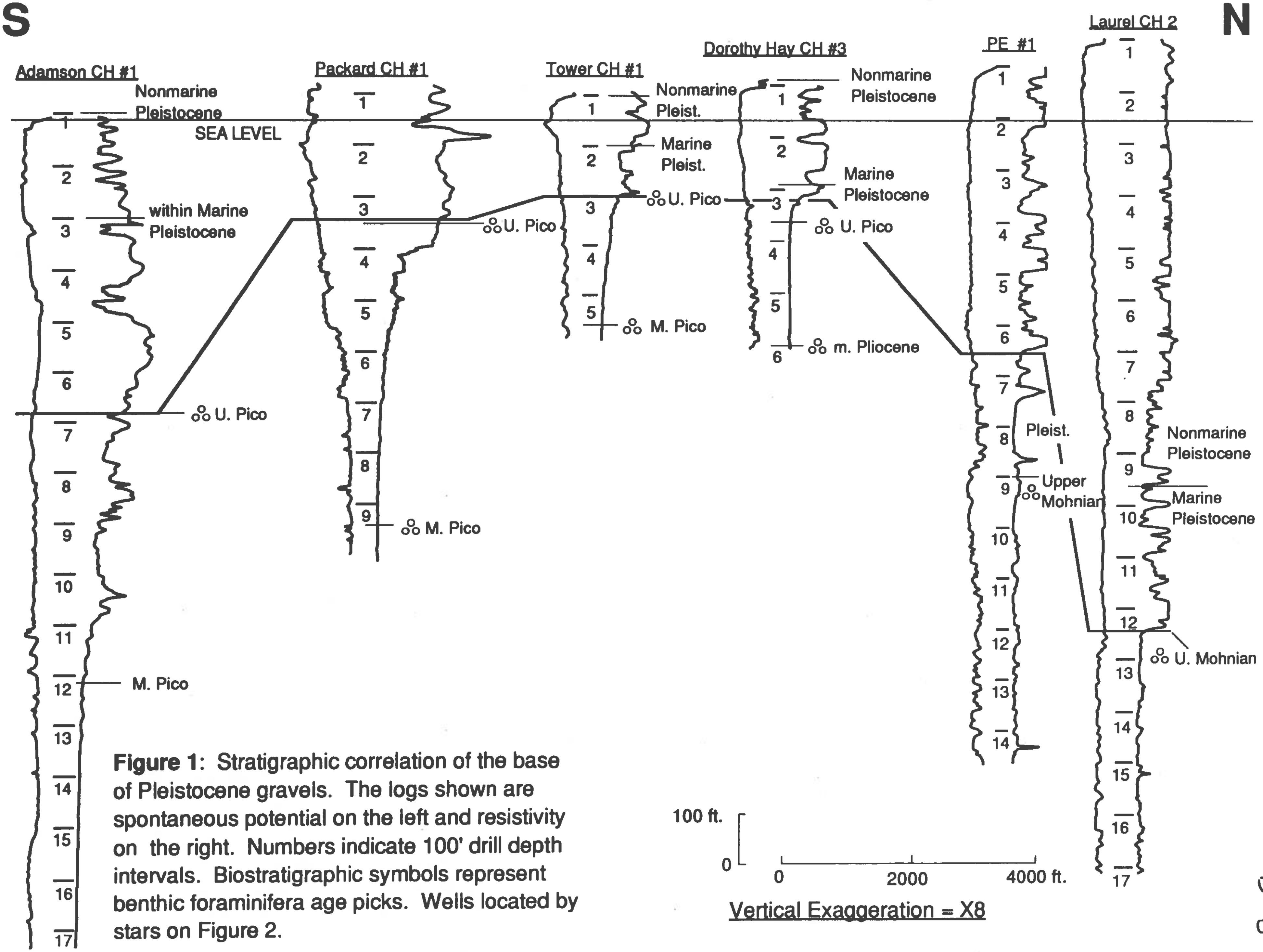


Figure 1: Stratigraphic correlation of the base of Pleistocene gravels. The logs shown are spontaneous potential on the left and resistivity on the right. Numbers indicate 100' drill depth intervals. Biostratigraphic symbols represent benthic foraminifera age picks. Wells located by stars on Figure 2.

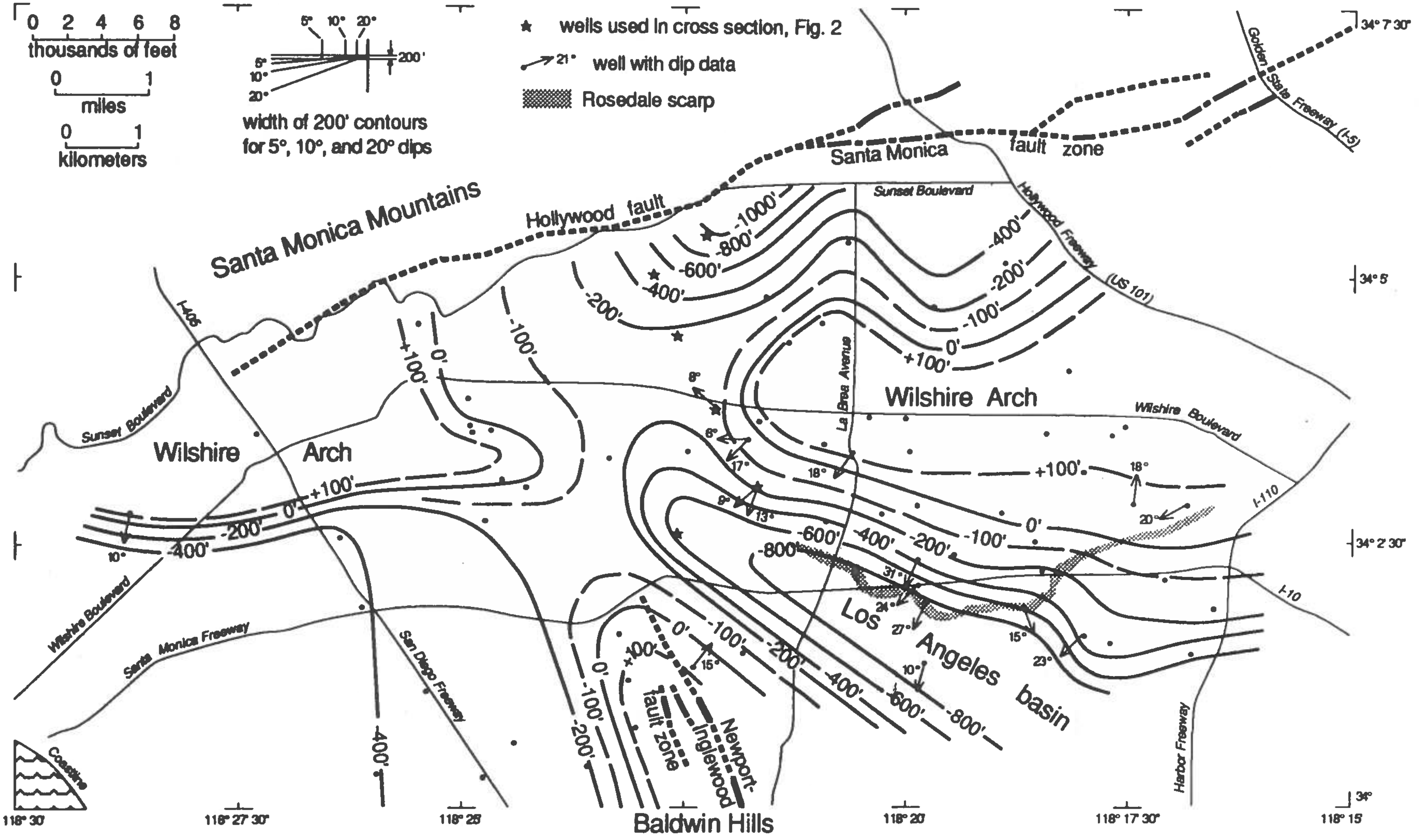


Figure 2. Structure contour map of the base of the Pleistocene gravels, northern Los Angeles basin (Beverly Hills and Hollywood 7.5' Quadrangles). Contour interval is 200' (solid lines), with supplemental contours at -100' and +100' (broken lines). Faults from Dibblee (1991 a,b).

D-9

D-10

SCEC Annual Summary Report, October 22, 1991

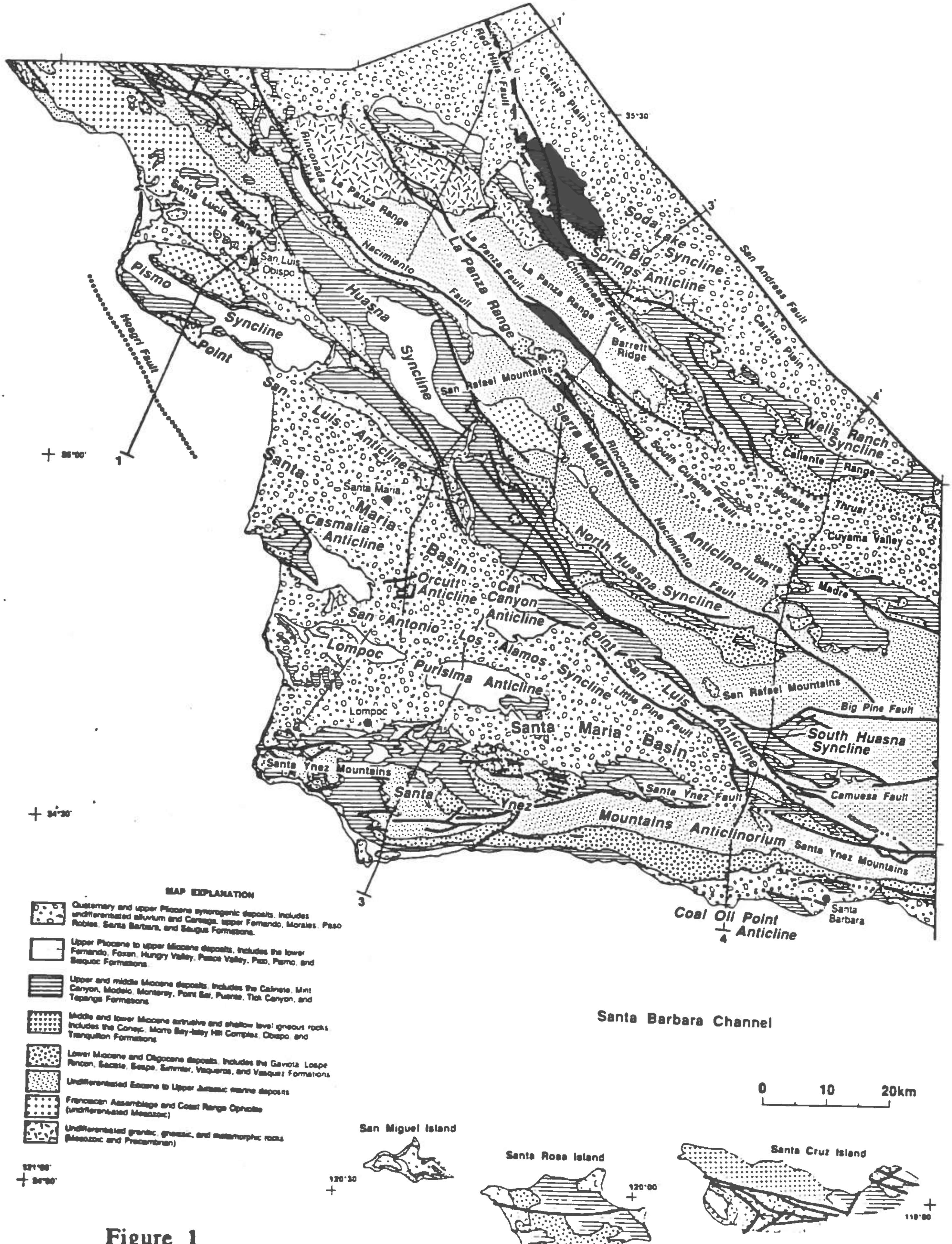
Seismic Potential of Thrust Faults of Southern California

Jay Namson and Thom Davis
Davis and Namson Consulting Geologists
Valencia, CA 91355

The objective of our work is to develop a regional subsurface map of southern California that shows the three dimensional geometry of late Cenozoic age deformation including thrust faults, thrust ramps, distribution of fault zone segments, and fault slip and convergence rates. The input data is a series of nine regional balanced cross sections and restorations (Davis et al., 1989; Namson and Davis, 1990 and1991) that have been constructed across southern California, and existing geologic, deep well, and geophysical data. Most of the cross sections extend from the Pacific Coast to the San Andreas fault (Figs. 1 and 2). These interpretations have focused on resolving the thrust fault geometries responsible for forming the late Cenozoic folds and convergence of the region. Our study for the SCEC was initiated in September 1991.

In order to develop a three-dimensional picture of the fault geometries data from these cross sections have been plotted on a regional base map at a scale of 1:250,000. In our initial work we have plotted the positions of the bottom and tops of ramps and focused on only those ramps that are responsible for the regional folds. We believe these ramp areas of the major thrusts to be the fault zones most capable of generating large earthquakes. Most of the ramp bottoms are at a hypothesized regional detachment at 13-16 km depths although some are at intermediate detachments of 6-8 km depth. In most cases the ramps are entirely buried such as the Elysian Park thrust below the Santa Monica Mountains anticlinorium or Point San Luis thrust below the Point San Luis anticline. Other thrust ramps extend to the surface such as the San Cayetano thrust in the Ventura basin and the Morales thrust in the Cuyama basin. In our map analysis we have tied together ramp tops and bottoms along strike between cross sections and have plotted total fault slip vectors and slip rates on the maps as derived from the cross sections. Over the remaining time period we are focusing on discontinuities in slip along strike and compare these with existing surface and subsurface geological maps and geophysical studies. The cross-strike discontinuites may reveal fault zone segmentations which are a major factor in estimating the size of future earthquakes. The thrust ramp map will also be a three-dimensional base for plotting and comparing regional seismicity and geodetic data with the regional thrust fault geometry.

D-11



Red Hills Fault
Carrizo Plain
1'
35°30'
Rinconada
La Panza Range
Santa Lucia Range
San Luis Obispo
Nacimiento
Soda Lake Syncline
Big Spring Anticline
3'
San Andreas Fault
La Panza Range
La Panza Fault
La Panza Range Fault
Chimeneas Fault
Pismo Syncline
Huasna
Fault
Hosgri Fault
Point
Syncline
San Rafael Mountains
Barrett Ridge
Carrizo Plain
San Luis Anticline
Sierra Madre
Rinconada
South Cuyama Fault
Wells Ranch Syncline
4'
Caliente Range
35°00'
1
Santa Maria
Santa Maria Basin
Casmalia Anticline
Morales Thrust
Cuyama Valley
Nacimiento Fault
Anticlinorium
Sierra Madre
North Huasna Syncline
Orcutt Anticline
Cat Canyon Anticline
San Antonio
Los Alamos Syncline
Lompoc
Purisima Anticline
Point San Luis Anticline
Little Pine Fault
San Rafael Mountains
Big Pine Fault
Lompoc
Santa Maria Basin
South Huasna Syncline
Santa Ynez Mountains
Santa Ynez Fault
Camuesa Fault
34°30'
Santa Ynez Mountains Anticlinorium
Santa Ynez Mountains
3
Coal Oil Point Anticline
4
Santa Barbara
MAP EXPLANATION
Quaternary and upper Pliocene synorogenic deposits. Includes undifferentiated alluvium and Careaga, upper Fernando, Morales, Paso Robles, Santa Barbara, and Saugus Formations.
Upper Pliocene to upper Miocene deposits. Includes the lower Fernando, Foxen, Hungry Valley, Peace Valley, Pico, Pismo, and Sisquoc Formations.
Upper and middle Miocene deposits. Includes the Caliente, Mint Canyon, Modelo, Monterey, Point Sal, Puente, Tick Canyon, and Topanga Formations.
Middle and lower Miocene extrusive and shallow level igneous rocks. Includes the Conejo, Morro Bay-Islay Hill Complex, Obispo, and Tranquillon Formations.
Lower Miocene and Oligocene deposits. Includes the Gaviota, Lospe, Rincon, Sacate, Sespe, Simmler, Vaqueros, and Vasquez Formations.
Undifferentiated Eocene to Upper Jurassic marine deposits
Franciscan Assemblage and Coast Range Ophiolite (undifferentiated Mesozoic)
Undifferentiated granitic, gneissic, and metamorphic rocks (Mesozoic and Precambrian)
121°00'
34°00'
120°30'
Santa Barbara Channel
0
10
20km
San Miguel Island
Santa Rosa Island
120°00'
Santa Cruz Island
119°30'

Figure 1

D-12

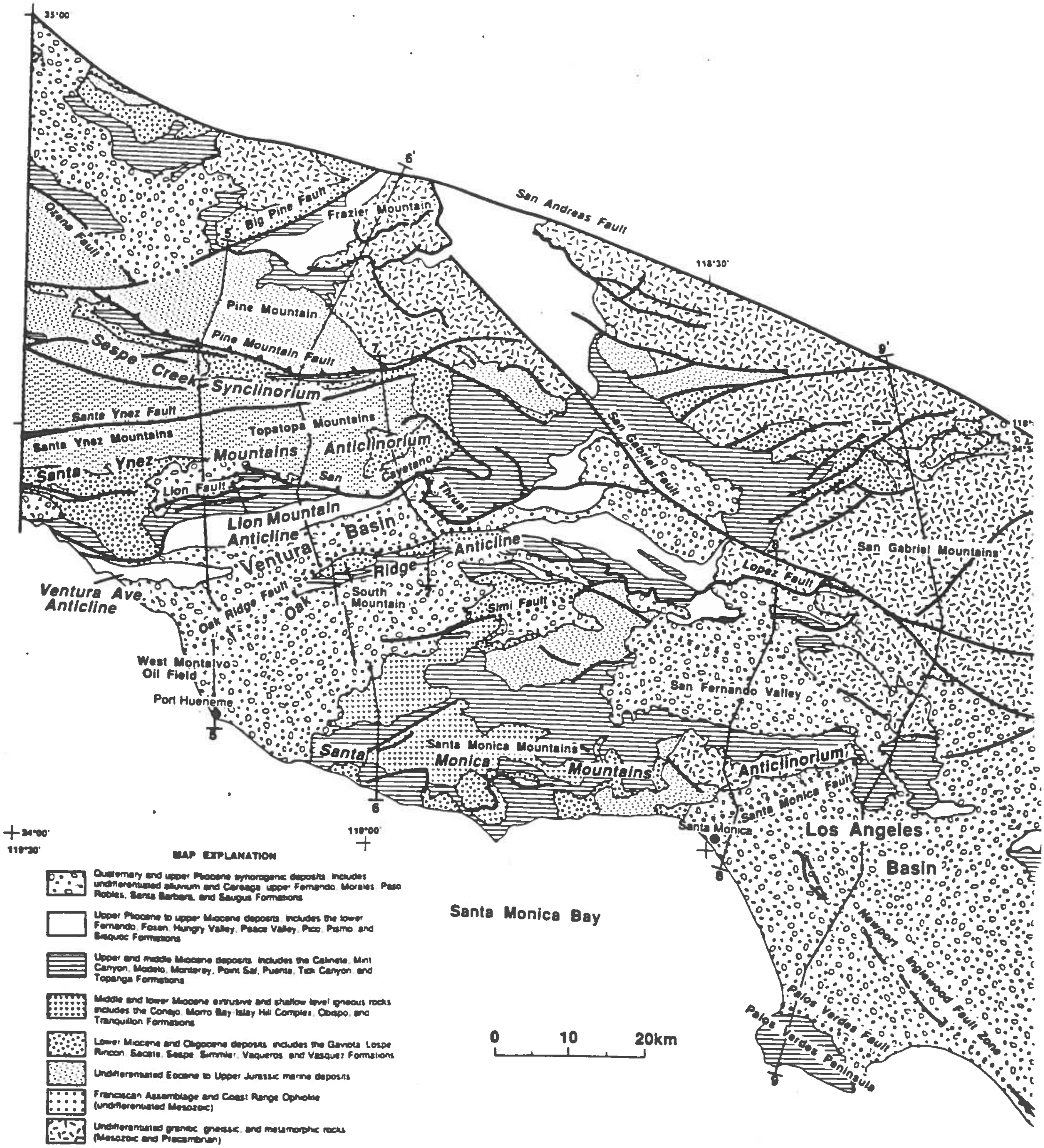

35°00'
San Andreas Fault
Big Pine Fault
Ozena Fault
Frazier Mountain
6'
5'
118°30'
Pine Mountain
Pine Mountain Fault
7'
9'
Sespe Creek Synclinorium
Santa Ynez Fault
Santa Ynez Mountains
Topatopa Mountains
Santa Ynez Mountains Anticlinorium
San Cayetano Thrust
San Gabriel Fault
Lion Fault
Lion Mountain Anticline
Ventura Basin
Oak Ridge Anticline
Ventura Ave. Anticline
Oak Ridge Fault
South Mountain
Simi Fault
8
Lopez Fault
San Gabriel Mountains
West Montalvo Oil Field
Port Hueneme
5
San Fernando Valley
Santa Monica Mountains
Santa Monica Mountains Anticlinorium
Santa Monica Fault
6
Santa Monica
Los Angeles Basin
8
Newport Inglewood Fault Zone
Palos Verdes Fault
Palos Verdes Peninsula
9
Santa Monica Bay
0
10
20km
34°00'
119°30'
118°00'
MAP EXPLANATION
Quaternary and upper Pliocene synorogenic deposits. Includes undifferentiated alluvium and Careaga, upper Fernando, Morales, Paso Robles, Santa Barbara, and Saugus Formations
Upper Pliocene to upper Miocene deposits. Includes the lower Fernando, Foxen, Hungry Valley, Peace Valley, Pico, Pismo and Sisquoc Formations
Upper and middle Miocene deposits. Includes the Calnete, Mint Canyon, Modelo, Monterey, Point Sal, Puente, Tick Canyon, and Topanga Formations
Middle and lower Miocene extrusive and shallow level igneous rocks. Includes the Conejo, Morro Bay Islay Hill Complex, Obispo, and Tranquillon Formations
Lower Miocene and Oligocene deposits. Includes the Gaviota, Lospe, Rincon, Sacate, Sespe, Simmler, Vaqueros, and Vasquez Formations
Undifferentiated Eocene to Upper Jurassic marine deposits
Franciscan Assemblage and Coast Range Ophiolite (undifferentiated Mesozoic)
Undifferentiated granitic, gneissic, and metamorphic rocks (Mesozoic and Precambrian)

Figure 2

D-13

Analysis and Inversion of Teleseisms

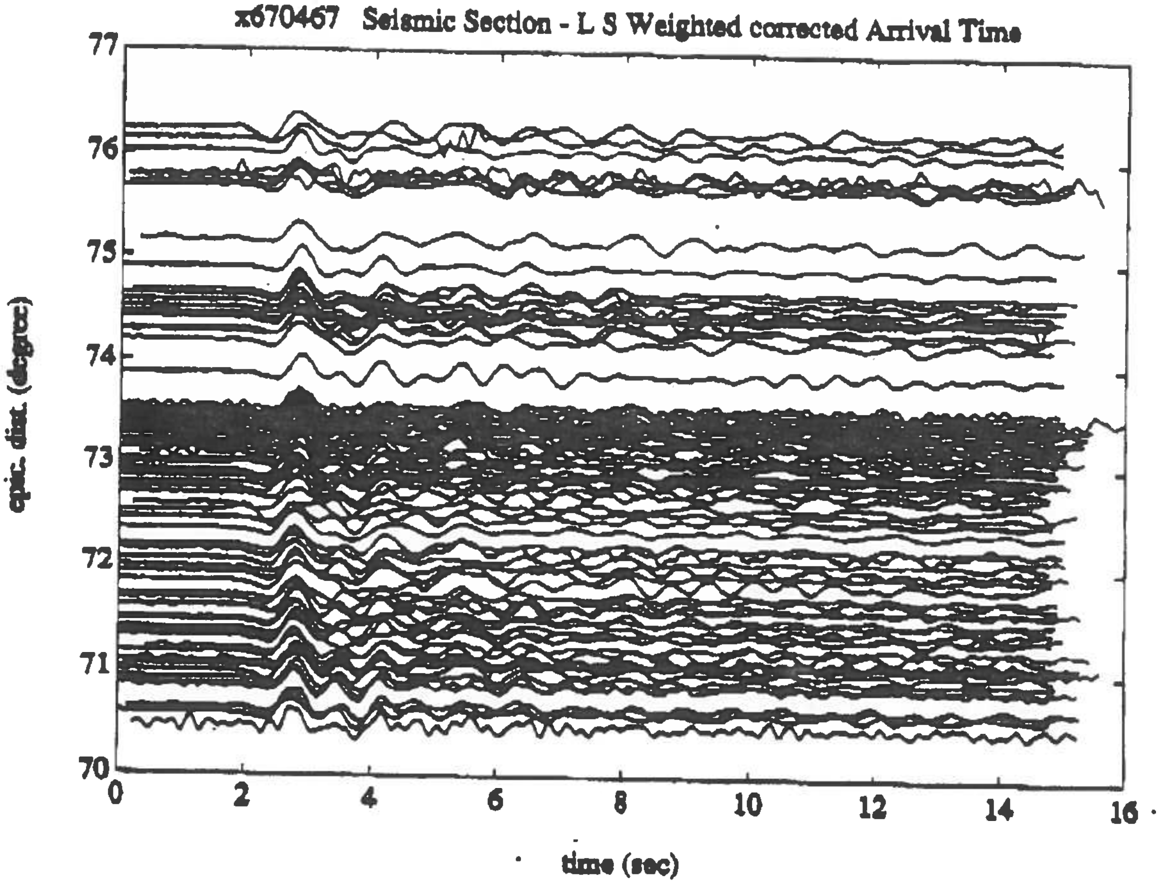
Paul M. Davis, UCLA

The objective is to use teleseismic phase times and waveforms to image lateral variation in southern California. With the assistance of Jim Mori (USGS) UCLA graduate student Herbert Rendon has acquired data from, and begun analysis of, 13 well-recorded teleseisms at the more than 200 sites of the southern California network. Semblance analysis has been used to stack waveforms to form a beam. A least squares technique which maximizes cross-correlation between nearby stations has been used to correct for local statics (figure 1). First arrival travel time residuals have been calculated (figure 2a). Travel time anomalies associated with the Salton trough and transverse ranges can be seen in the residuals, as has been seen by others (Hadley and Kanamori, 1977; Raikes, 1980; Humphreys and Clayton, 1990). The next step involves systematically stripping of crustal and uppermost mantle effects using the model of Sung (1989), Sung and Jackson (1991, in press) which is based on arrival times of Pg and Pn waves; Then inversion for upper mantle anomalies.

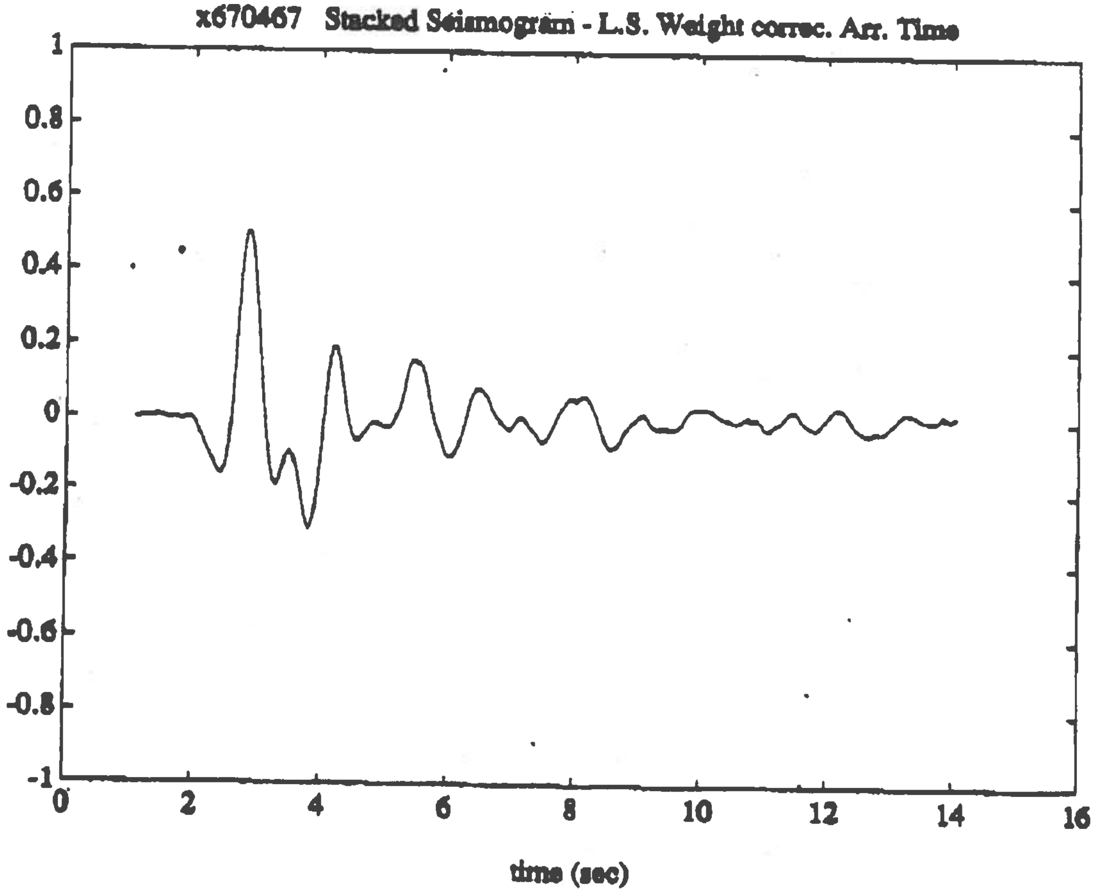
Our search for coherent scatterers in the teleseismic coda has begun by examining the cross-correlation between individual stations and the average waveform found from the semblance beam stack. When high noise stations are excluded, it is anticipated that degraded correlation will occur where scattered radiation is greatest. Figure 2b shows our first attempt to search for spatially coherent variation in correlation. Two regions stand out, the Mojave and The Sierras. The next step will involve a systematic search for scatterers using the method of Hedlin et al., (1991) who detected body - Rayleigh scattering SW and E of the NORESS array. We propose to search for body-body scattering also.

As preparation for a large scale imaging experiment in southern California, we have purchased a Reftek recorder (UCLA matching funds) and have installed it, on and off, at a site at Frazier Park. We propose to purchase a further 2 instruments and to install at sites in the San Gabriel Mountains in preparation for an imaging transect that has been proposed. We will then have students familiar with the instruments and sites permitted for aftershock studies, should the need arrive.

D-14



x670467 Seismic Section - L S Weighted corrected Arrival Time

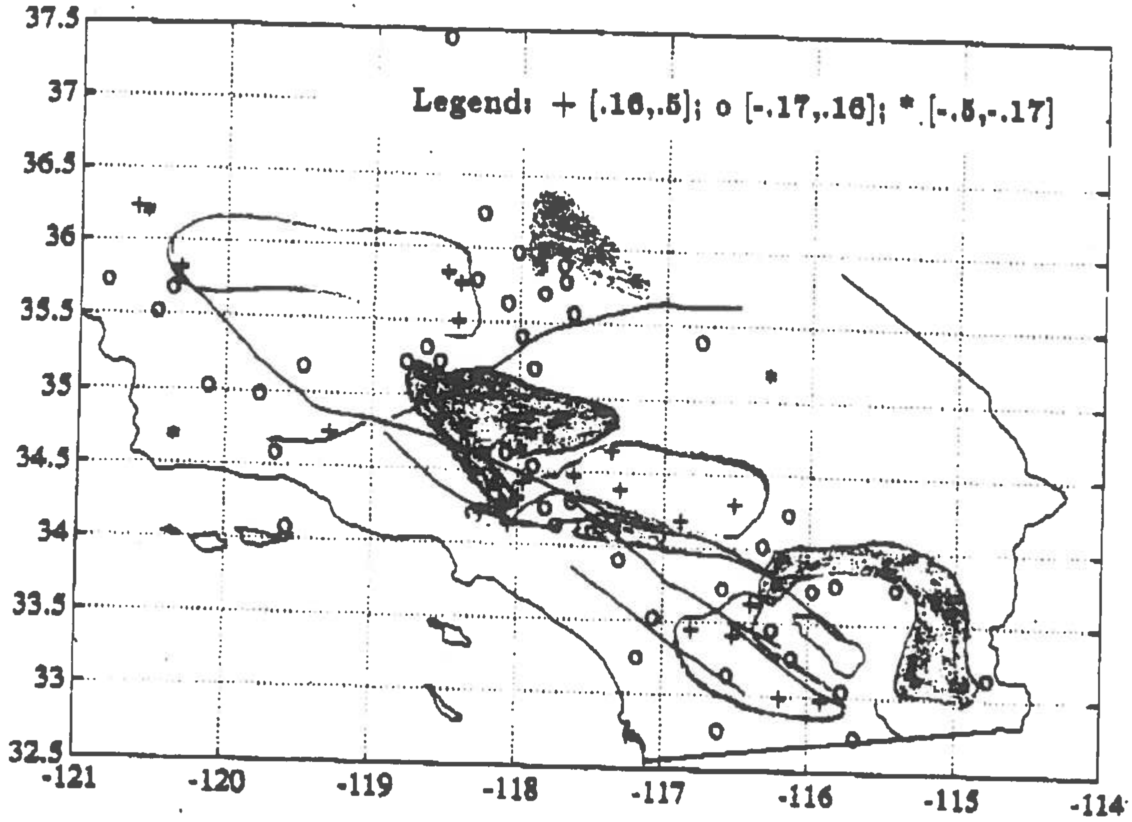


x670467 Stacked Seismogram - L.S. Weight correc. Arr. Time

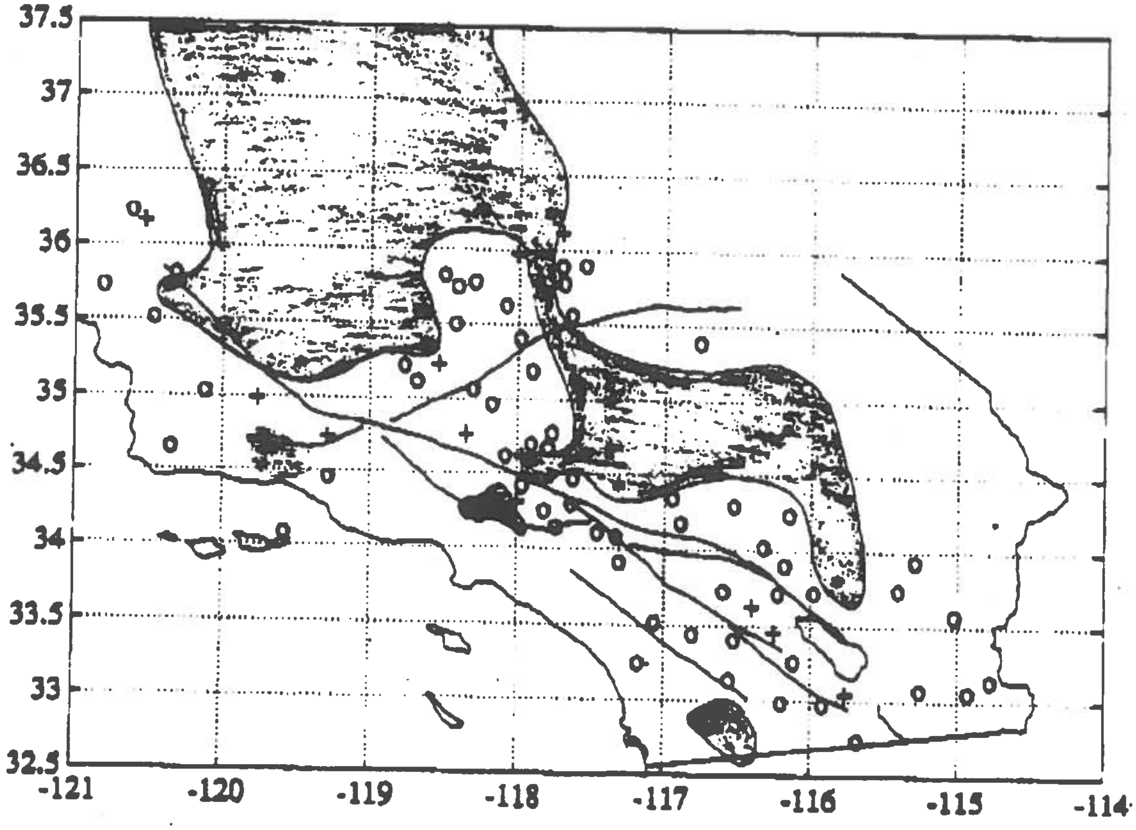
2

D-15

Arrival Times Residuals Map



Cross-correlation Map



Legend: + [.92,1.]; o [.85,.92]; * [.8,.85]

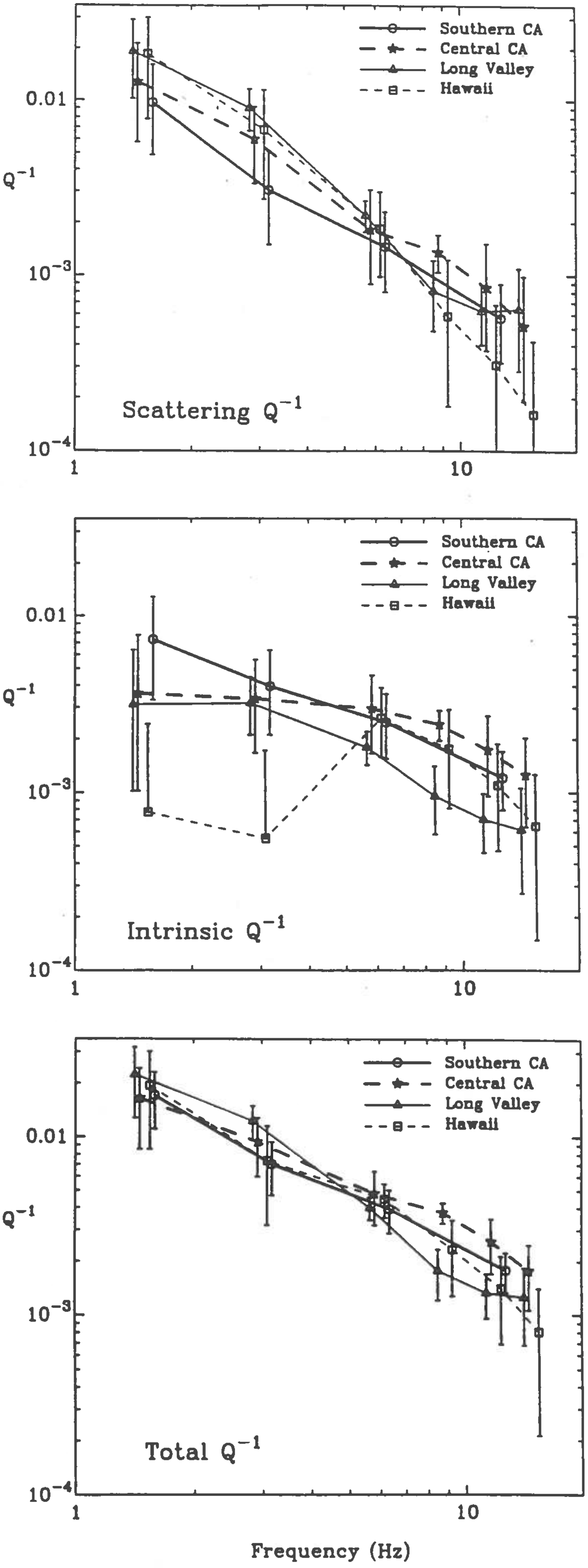
D-16

A Comparative Study of Scattering and Intrinsic Q^{-1} for Hawaii, Long Valley, Central and Southern California Between 1.5 and 15.0 Hz.

by Kevin Mayeda, Stuart Koyanagi and Keiiti Aki

A new method recently developed by Hoshiba *et al.* (1991) was used to separate the effects of scattering Q^{-1} and intrinsic Q^{-1} from an analysis of the S-wave and its' coda in Hawaii, Long Valley, central and southern California. Unlike the method of Wu (1985), which involves integration of the entire S-wave energy, the new method relies on the integration of the S-wave energy for three successive time windows as a function of hypocentral distance. Using the fundamental separability of source, site and path effects for coda waves, we normalized the energy in each window for many events recorded at many stations to a common site and source. We plotted the geometric spreading-corrected normalized energy as a function of hypocentral distance. The data for all three time windows were then simultaneously fit to Monte-Carlo simulations assuming isotropic body wave scattering in a medium of randomly and uniformly distributed scatterers and uniform intrinsic Q^{-1}.

The figures show the frequency-dependent scattering, anelastic and total Q^{-1}. To show the accuracy of the model fitting, the vertical error bars give the range in Q^{-1} at the 90% confidence level using the F-distribution for 40 degrees of freedom. Within the error bars, results from southern California agree with those from the other regions. Despite the rather large error bars we can make some general conclusions on the nature of attenuation in all four regions. In general, for frequencies less than or equal to 6.0 Hz, scattering Q^{-1} is greater than intrinsic Q^{-1}, whereas above 6.0 Hz the opposite was found. We found that in all four regions the scattering Q^{-1} is strongly frequency dependent, decreasing proportional to $f^{-1.4}$ to $f^{-2.0}$, whereas the anelastic Q^{-1} is considerably less frequency dependent.


Southern CA
Central CA
Long Valley
Hawaii
0.01
Q^-1
10^-3
10^-4
1
10
Scattering Q^-1
Southern CA
Central CA
Long Valley
Hawaii
0.01
Q^-1
10^-3
10^-4
1
10
Intrinsic Q^-1
Southern CA
Central CA
Long Valley
Hawaii
0.01
Q^-1
10^-3
10^-4
1
10
Total Q^-1
Frequency (Hz)

D-18

Progress report on
Field Study of San Andreas fault zone structure from Parkfield to Salton Sea using 3-component long-period microseisms.

Kei Aki and Valerie Ferrazzini, USC

We proposed to collect microseisms data along the San Andreas fault to determine the variation in the fault zone structure by studying the long-period anisotropic amplification relative to the fault strike in the range of 1 to 8sec. We have selected 13 sites, shown in Figure 1, along the northern part of the San Andreas fault, from San Juan Bautista to Cayuma. At these sites we will set up one instrument outside the fault zone as reference site and a second instrument will be set up at varying distance from the first one, in a direction perpendicular to the fault.

To carry out this experiment, we needed to improve our recording system and rather than to modify our old MIT-built digital tape recorders, we have developed a new instrument with a size of a lunch box. The recording system is a tattletale data logger built by Onset Computer Corporation. It is equiped with 8 analog input pins connected to a 12-bit analog to digital converter with a conversion time of 2.5 microseconds and an internal clock.

Input from the 3-component, 1Hz geophone, is first passed through an equalizer which extends the response of the geophone to 10 sec. It is then amplified, at gain of 10, 100, or 1000, and filtered according to the sampling rate before being digitized. The data are recorded on a 20Mbyte hard disk, which corresponds to about 10 hours of continous recording at a sampling rate of 100 samp/sec. The power may be supply externally or by lithium batteries placed inside the box of the recorder which should last two weeks in the field.

To operate the instrument one must first program the Onset. This is done using a Macintosh and consist in loading different programs to set up the time from an external clock and the time and duration of the recording windows. The instrument is then left in the field, and two other programs are used to obtain a time correction and to unload the data files recorded. These instruments will be easily adapted for the purpose of other experiments by developing new softwares for the Onset to operate in triggering mode.

At the present time the instruments are being tested at USC and the field experiment will start in early November. The spectral analysis of the data will be done as the data are collected.

D-19

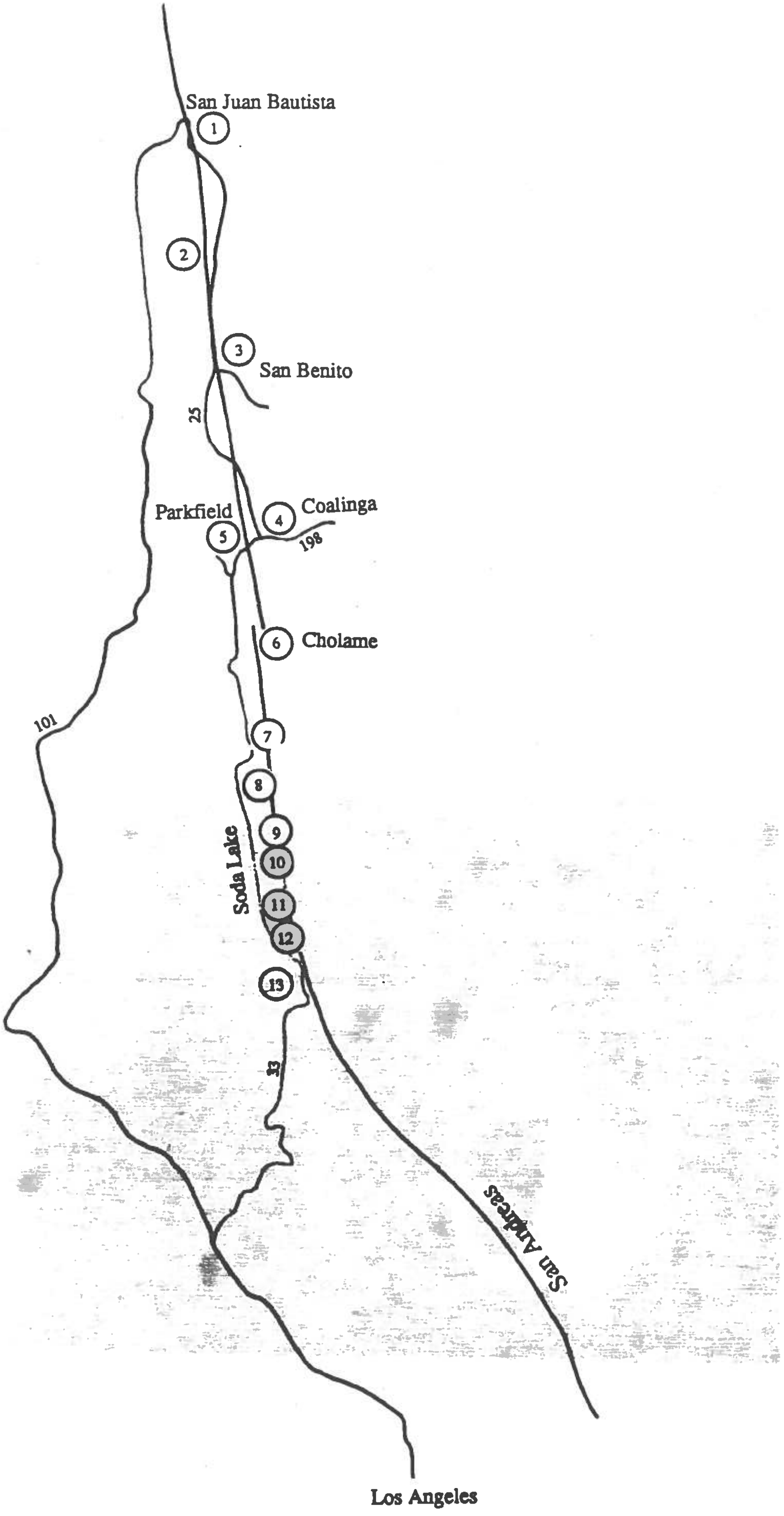

San Juan Bautista
1
2
3
San Benito
25
Parkfield
4
Coalinga
5
198
6
Cholame
101
7
8
9
10
Soda Lake
11
12
13
33
San Andreas
Los Angeles

Fig 1

D-20

SCEC Research Statement, October 1991

Peter Leary
Geological Sciences, University of Southern California

Observation of the crust has shown power law distributions characterize earthquake sizes (Gutenberg-Richter relation), earthquake spatial separations ('Kagan-Knopoff' relation [1]), and fracture density fluctuations in crystalline rock (Hurst rescaled range [2]). Physical phenomena giving rise to power law distributions are, within limits, independent of the size scale on which the phenomena occur [3]. Physical systems in which elements interact over a large range of scale lengths are recognized to be 'critical systems' and can be highly unpredictable [4]. Brittle fracture in crustal rock is evidently a process in which large scale or catastrophic failure can be precipitated by a relatively small sequence of failures. To turn these seismic data on the nature of crustal mechanics to scientific and civic use there is a need to observe hazardous fault seismic activity over as large an earthquake scale range and with as much spatial resolution as is feasible.

There are related four aspects to achieving spatial resolution of fault zone microearthquakes: 1) sensitivity to small events; 2) fixing event spatial occurrence in relation to the fault using fault zone trapped waves; 3) recording P and S head waves; 4) achieving good velocity models of the fault study volumes. The 8 station 3-component Parkfield borehole seismic network provides an excellent starting point for such investigations: events are recorded down to magnitude -1 [5]; at least one borehole station records direct fault zone trapped waves [6,7]; fault zone P head waves are well resolved and 3-component data allows the possibility of recognizing S head waves [8]; there are well advanced velocity model inversions [9].

To illustrate spatial clustering of Parkfield microearthquakes, consider the distribution of events located within a planar volume near the fault (Fig. 1). A fractal dimension $D = 1.3$ creates the simulated clustering that most nearly reproduces the visual clustering (Fig. 1a) and the statistics of clustering (Fig. 1b). The equivalent fractal dimension for a cubic volume is $D = 2.3$; this fractal dimension is observed in deep borehole log fracture density fluctuations and is consistent with Gutenberg-Richter b-values of about 1.1 to 1.15 [2]. Relocated Parkfield events using superior velocity models, head wave data, and constraints from trapped wave observations will allow a more precise investigation of Parkfield event clustering as a function of time and space.

Interpreting seismic trapped wave observations at Parkfield requires the ability to model trapped waves in complex waveguide structures. Simulations of seismic trapped wave propagation in geometrically irregular low velocity fault structures with possibly non-uniform low velocity distributions were conducted this summer on the massively parallel Connection Machine at the Institute de Physique du Globe [7]. The simulations demonstrated that at wavelengths appropriate to the San Andreas fault at Parkfield, fault zone trapped waves propagate easily in velocity structures that are geometrically complex provided the low velocity material properties do not change significantly. This means that an irregular fault zone consisting of a uniform fault gouge can be approximately modeled with numerical methods based on a uniform planar parallel waveguide [10]. Fig. 2a shows that it is possible to match observed Parkfield fault zone trapped wave observations with a 150-250 m wide core low velocity ($V_S \sim 1.8$-2.0 km/s) layer. A 150-250 m wide fault zone is incompatible with trapped wave excitation (Fig. 2b) by the three events with locations shown in Figs. 2c. Constraining such event groupings to lie on a narrow fault will provide better velocity models and event locations.

[1] Kagan Y. Y. & L. Knopoff (1980) *Geophys. J. R. astr. Soc. 62*, 303. [2] Leary P. C. (1991) *Geophys. J. R. astr. Soc. 107*. [3] King G. G. P. (1983) *Pageoph 121*, 761; Meakin P. (1991) *Science 256*, 226. [4] Bak P. & C. Tang (1989) *J. Geophys. Res. 94*; 15635. [5] Malin P. E. et al. (1989) *Science 244*, 557. [6] Li Y.-G. & P. Leary, *BSSA 80*, 1245. [7] Leary P. C. et al. (1991) *Proc. Conf. 'Earthquake Prediction: State-of-the-Art*, Strasbourg. [8] Ben-Zion Y. & P. E. Malin (1991) *Science 251*, 1592. [9] Michelini A. & T. V. McEvilly (1991) *BSSA 81*; 524; Lees J. M. & P. E. Malin (1990) *J. Geophys. Res. 95*, 21793. [10] Ben-Zion Y. & K. Aki (1990) *BSSA 80*, 971,

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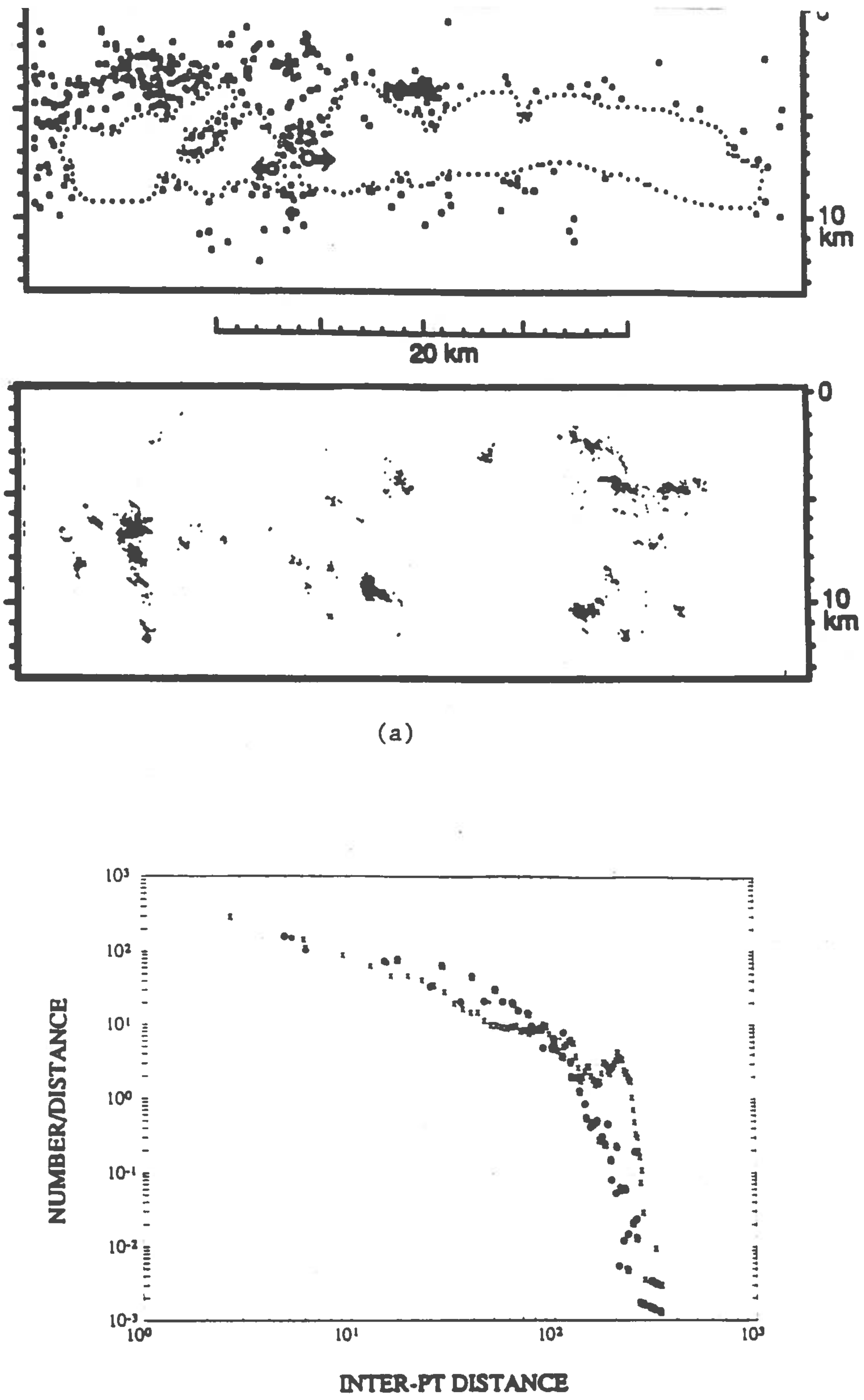
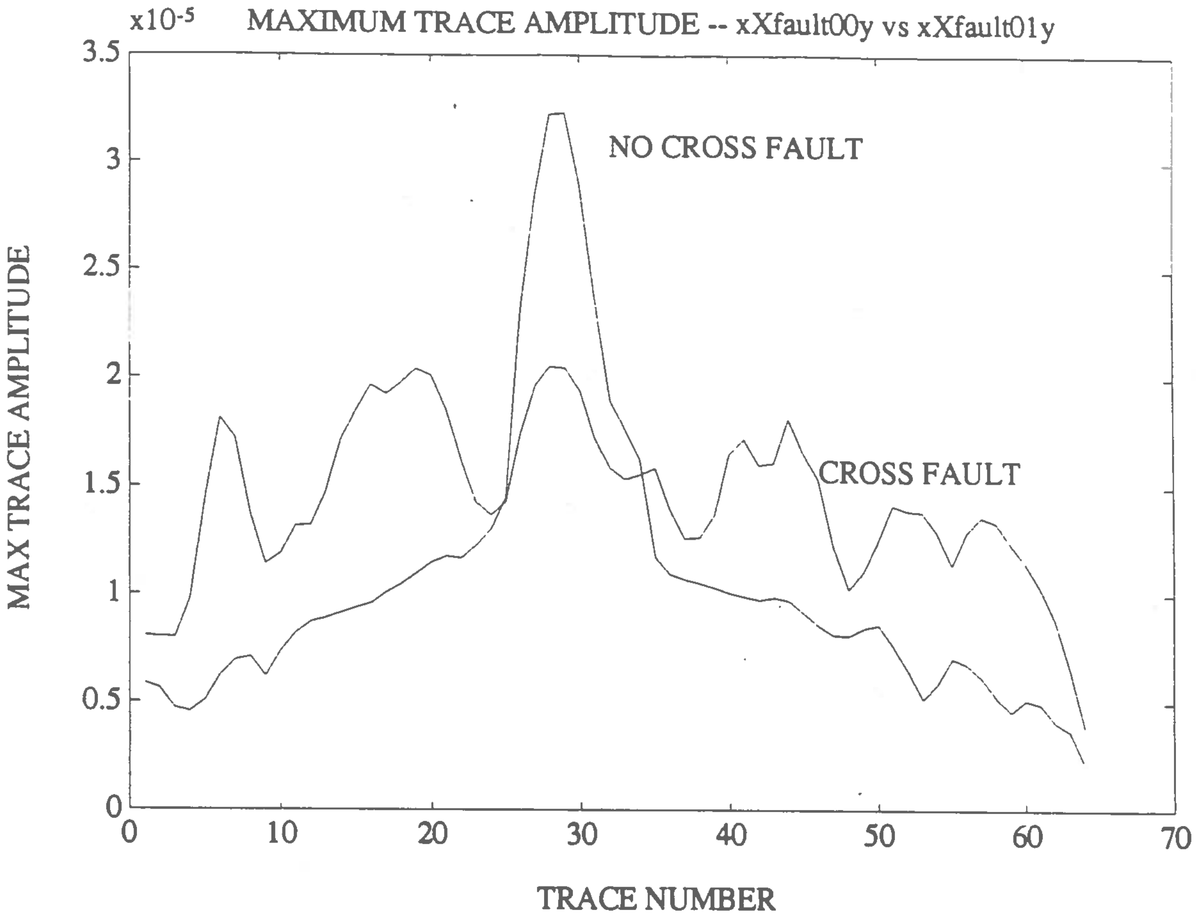


(a)

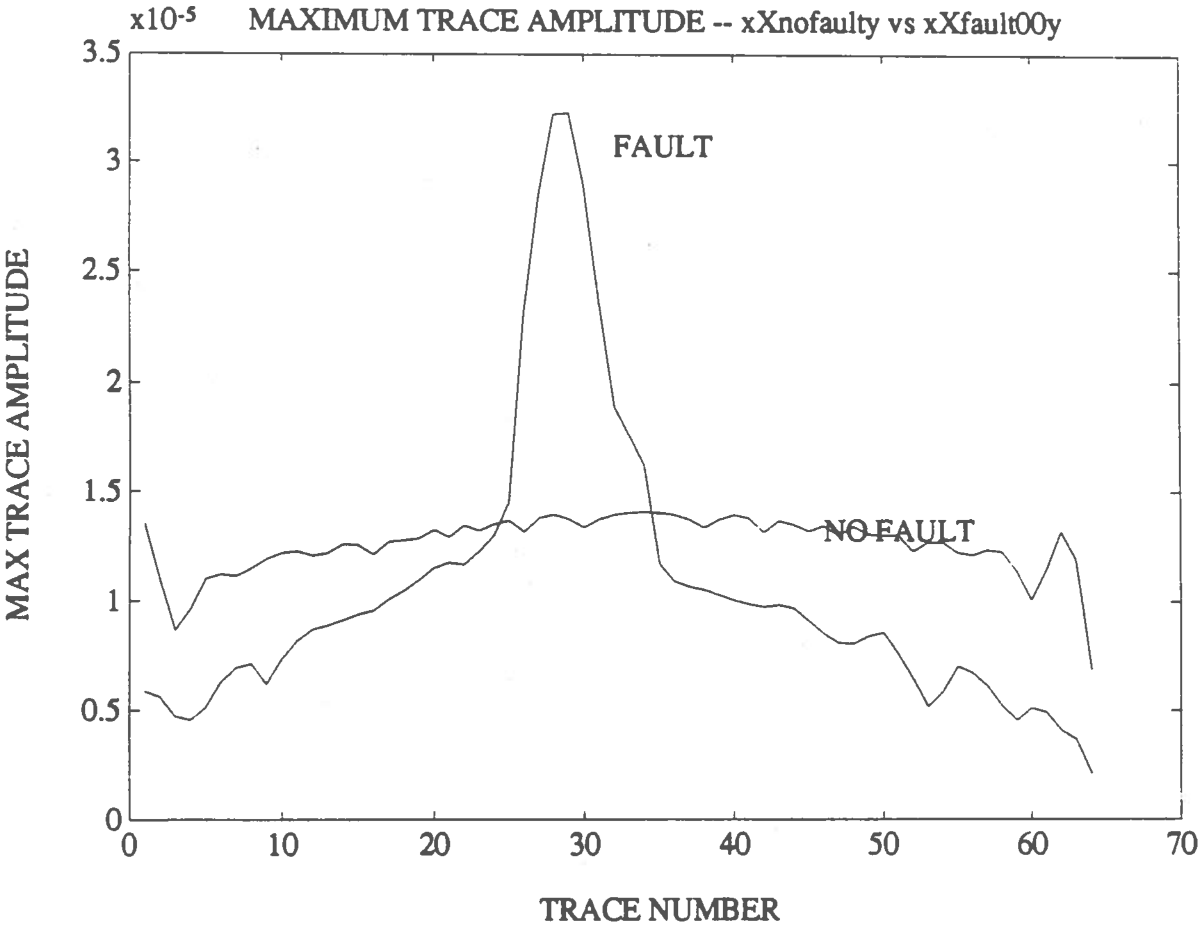
(b)

Figure 1. (a) Comparison between the distribution of Parkfield microearthquakes (above) and a synthetic fractal distribution of points (below). The synthetic distribution has a fractal dimension of D = 1.3. (b) The frequency distribution of inter-event distances of Parkfield earthquakes (solid dots) and inter-point distances from the synthetic distribution (x's). The distribution of Parkfield events is given by Malin et al. [5].

D-21



x10-5
MAXIMUM TRACE AMPLITUDE -- xXfault00y vs xXfault01y
MAX TRACE AMPLITUDE
TRACE NUMBER
NO CROSS FAULT
CROSS FAULT
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70



x10-5
MAXIMUM TRACE AMPLITUDE -- xXnofaulty vs xXfault00y
MAX TRACE AMPLITUDE
TRACE NUMBER
FAULT
NO FAULT
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70

D-22

Report on Experiment of Fault Zone Trapped Waves

Yong-Gang Li/Ta-Liang Teng, USC, Group D (Subsurface Imaging)

We have prepared for the field experiment, "*The observation of fault zone trapped waves at the San Jacinto fault at Anza, southern California*" funded by SCEC. The deployment of 6 PASSCAL instruments will be completed on schedule in November for six month data logging. The location for instrument deployment has been carefully selected based on the following criteria:

1. The location should be within or close to the surface trace of fault zone. The appropriate offset range is between 0 and 500 m. The numerical modeling shows that the amplitude of fault-zone trapped waves decreases rapidly as the distance from the fault increases.
2. The location should be in the segment of fault zone that is characteristic of a wave-guide, i.e. a narrow fault gouge sandwiched by basement outcrops on both sides. The appropriate width of fault zone is between tens and hundreds of meters. The numerical modeling shows that this width range is preferable to record fault-zone trapped waves using 1 Hz recording system.
3. The location should not be in the area where the basement is overlain by a thick sedimentary or weathering layer (thicker than 50 m). The numerical modeling shows that the surface low velocity layer will destroy the vertical fault-zone trapped waves even if they are excited by appropriated seismic events.
4. The location should be in the seismicity area so that we can obtained enough waveform data during six months of instrument deployment. The numerical modeling shows that 5-15 km distance range from the earthquake source region is appropriate for both amplitude and phase information of fault-zone trapped waves.
5. The instruments should be placed in safe places, indoor or in the container.

The above criteria are crucial to observe fault zone trapped waves using surface recording stations. During the past three months, we have achieved the following things:

1. The appropriate locations for instrument deployment have been selected after geological survey in the areas of interest.
2. Six units of PASSCAL instruments are available during November to May, shipped from IRIS center or SCEC.
3. Four units of them will be placed inside structures of Mussall, Gerble, Mader and O'leary properties, two units on the Smith's farm, all private properties. The permits have been granted by the former four owners, and we still keep in touch with Smith.
4. We have being training to use PASSCAL instruments.
5. The event locations will be obtained from UCSD catalogue with the help of Frank Vernon.

D-23

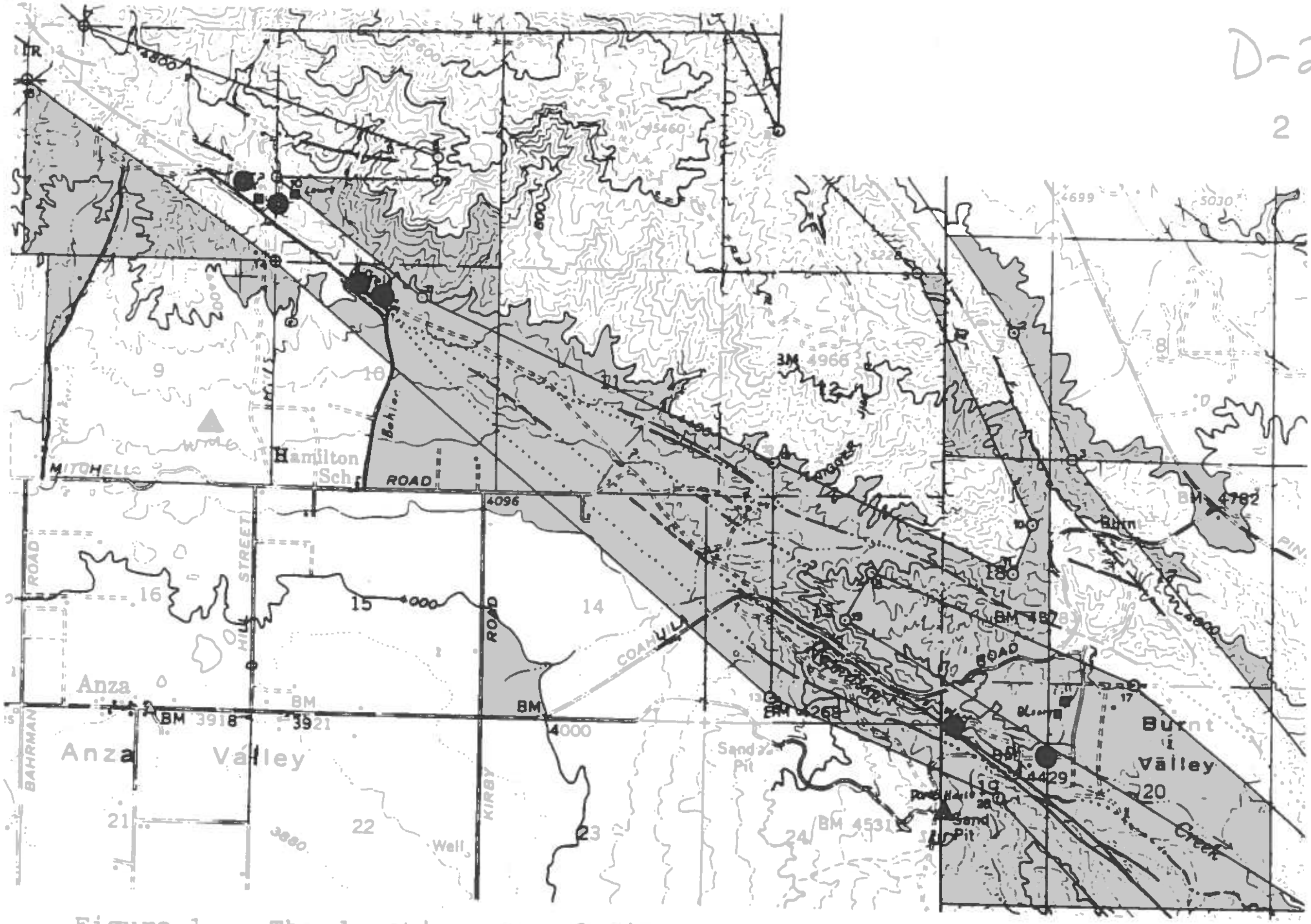


Figure 1 The location map of six PASSCAL instruments (circles) for observation of fault-zone trapped waves at the San Jacinto fault, Anza, southern California.

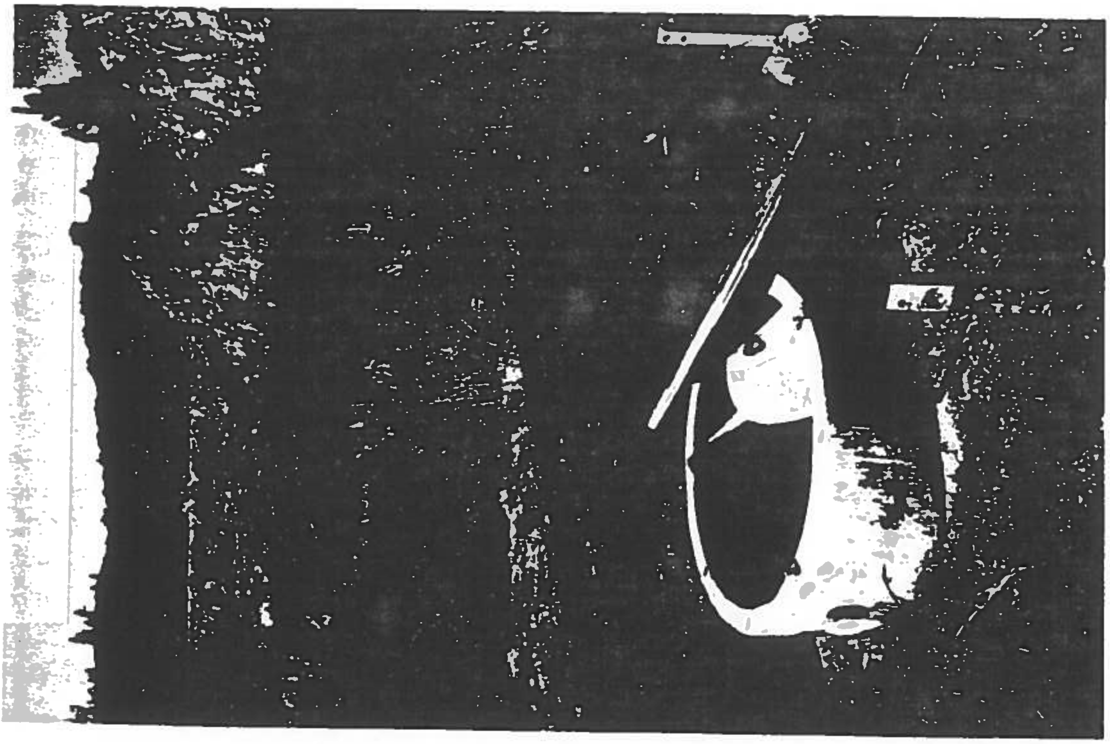


Figure 2 An abandoned dry well within the trace of fault zone is an appropriate place for instrument deployment.

D-24

Summary Report - October 1991

Program: Crustal Framework for the Master Model: Collection and 3-D Visualization of Geophysical and Tectonic Data for Southern California

P.I.'s: David Okaya and Tom Henyey

Objectives of this research program:

(a) develop a database of geological and geophysical information to define a crustal framework for the master model.
(b) determine the best available methodology to display and visually juxtapose such data (academic or commercial computer hardware/software).
(c) make database and visualization capability available to all SCEC institutions

Efforts thus far for this program have focussed on the first two objectives as stated above. We are currently assembling a preliminary set of 2-D and point data which can be used (a) to define the crustal framework of Southern California and (b) to fully examine graphical visualization systems. Full accumulation of different regional geological and geophysical datasets will occur once we have determined the capabilities of the visualization platform.

The initial data sets which are most easily obtainable are digital topography and bathymetry, and regional gravity and magnetics. Initial attempts are being made to obtain these data at either no or little cost. Currently, we have an arrangement to obtain from the USGS regional (gridded) Bouguer gravity of Southern California at no cost. Gridded digitial topography (Digital Elevation Model or DEM) is available from the USGS at some cost. Such data are available at various spatial sampling intervals: 30 m x 30 m, 2 arcsec x 2 arcsec, 2 arcsec x 3 arcsec and 3 arcsec x 3 arcsec and in 7.5 min, 15 min, 30 min, and 1 degree increments. These DEM data will be purchased if necessary, however we will try to obtain them via the community if possible (will discuss with UCSB and JPL). A set of offshore California bathymetry data is already inhouse; discussion with the USGS for a more complete set is also underway.

Visualization software which have been considered include Startdent AVS, JPL Vicar, WAVEFRONT, SUN packages such as SunPHIGS, SunGKS, and SunVISION. These software provide to various degrees of sophistication oblique-perspective views of planar and/or volumetric data. The ultimate goal is to determine a software-hardware configuration which will allow for the simultaneous display of multiple data sets (i.e., a 3-D block of land-use draped over topography roughness with hypocenters located spatially at depth). The software application must (a) be easy to use, (b) be capable of rendering planar and volumetric data sets, (c) work on different computer platforms in use at SCEC institutions, (d) be able to accept very diverse data types and formats, (e) be competitive regarding site and SCEC-wide group licensing, and (f) be able to exchange data with ArcInfo. It is desired to be able to share data with ArcInfo so that GIS data can be incorporated into three-dimensional displays using this visualization system. Stardent AVS is the leading candidate to be the software to be used for this application. Consultations with UCSB and JPL will be made before a software application is selected.

D-25

Velocity Structure of the Greater Los Angeles Basin

R. Clayton and E. Hauksson
Caltech

The object of this study is to determine the large scale velocity and structural features of the greater Los Angeles Basin from travel time inversions and waveform data. The primary source of the data is the picked events produced by the SCSN and the archived seismograms.

This study is at a very preliminary stage and to date has concentrated on assembling and reformatting the data. We have now obtained a complete phase catalogue for 1984 to 1990 in a form that can be used on Unix computers, and are now starting to construct profiles across the basin. The latter step is now possible because the mass-storage component of the data center is now (almost) operational.

Group E: Crustal Deformation

Group Leader: Dave Jackson

E-1

Extremal Fault Slip Models for Southern California from 15 Years of USGS Trilateration Data

Hadley Johnson

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Scripps Institution of Oceanography, 0225,
University of California, San Diego, La Jolla CA 92093

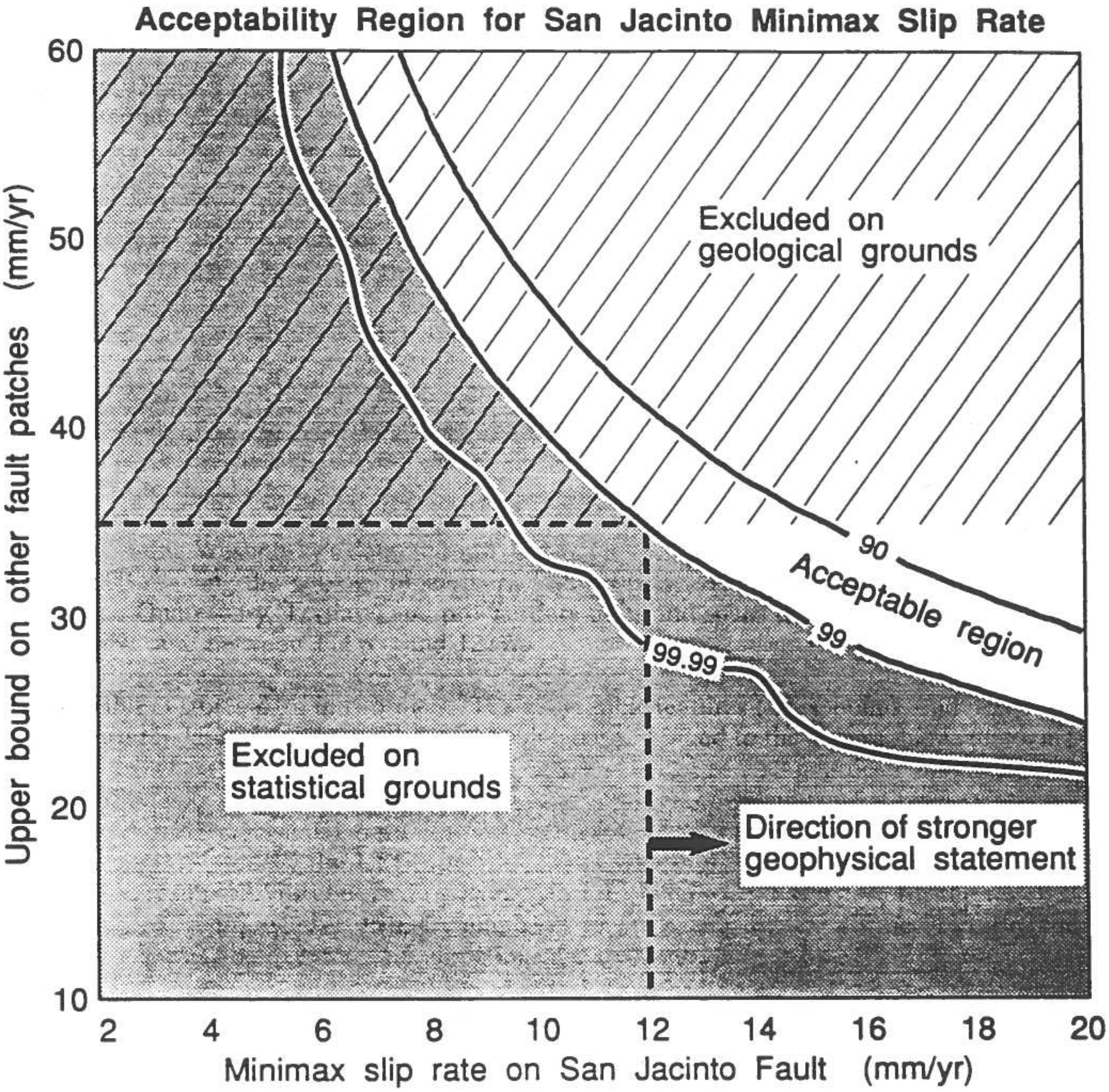
The USGS geodolite measurements made over the past 15 years throughout southern California provide an unequaled measurement of crustal deformation in the area. We have used several different techniques to investigate what this dataset can resolve about the distribution and rate of interseismic slip on the faults of the San Andreas system. Most recently we have developed a procedure to invert for extremal models to try to better pin down the rates of slip. Instead of trying to determine the complete slip distribution on each fault (which requires hundreds of model elements to be found), we invert only for the minimum value of the maximum slip rate on each fault: the "minimax" slip rate.

In this procedure we seek the slip model s that minimizes the misfit $\|\Sigma^{-1}(d - A\,s)\|_E$ subject to the constraint $0 \le s_i \le u$. Where d is the vector of line-length rates of change, Σ is the covariance matrix of the measured data, A is a matrix of partials which relates the slip on an individual fault patch to a change in line-length, and u is a vector of upper bounds on the model elements. (The model elements s_i are also constrained to be greater than or equal to zero which means that only right-lateral movements are allowed on the fault patches.) In this way, each model element is constrained to lie between both a lower bound and an upper bound—thus the technique name "bounded value least squares." The general strategy employed is to impose a different upper bound on each fault and then let the algorithm calculate the least squares solution to the model. If the imposed bounds are very "loose" (large range of slip values allowed), the routine will have no difficulty fitting the data and will result in a small model misfit—since this is still an underdetermined problem, it is quite possible that the misfit will be 0. On the other hand, with tight bounds on all of the model elements (or perhaps only a select subset—and this is the virtue of the approach), the routine *will* have difficulty fitting the data adequately and may result in a model misfit (distributed as χ^2_N, where N is the number of measured data) which is deemed statistically unacceptible. In this latter case, we can then assume that at least one of our assumptions at the outset was incorrect. If we choose our assumptions (i.e. bounds on the model) so that all but one is non-controversial, we are left with the conclusion that this bound was incorrect.

By imposing a relatively loose upper bound on the slip patches on, say, the San Jacinto, Elsinore, and Newport-Inglewood faults and then progressively lowering the upper bound on the patches of the San Andreas Fault, we eventually come to a point where the data can no longer be satisfied (at some level of statistical confidence). At this point we say that we have determined the minimax slip rate for the San Andreas Fault. That is, there must be at least one fault patch on the San Andreas which must be slipping at a yearly rate greater than or equal to this value. We have calculated this minimax rate for each of the four southern California faults and have found values which are geologically reasonable for both the San Andreas and San Jacinto, and have found that the data are fit acceptably by a model in which either the entire Jacinto or Newport-Inglewood is held to no slip at all (though both cannot be simultaneously held to zero slip). The results for the San Jacinto are shown in the accompanying plot.

The minimax solutions also reflect *where* the algorithm wants to place the subsurface slip. As it turns out, this placement shows similarities to both our previous inversion results (though with different slip rates) and to the patterns of seismicity along the faults.

E-2



Contour levels are one minus the probability that the best-fitting inversion model would have had the calculated misfit level based solely on the error estimates for the geodolite data. To use this plot: select some prejudicial upper bound slip-rate to be imposed on all fault patches on the SAF, EF, and NIF on the vertical axis (e.g. 35 mm/yr), then trace horizontally to the intersection with an acceptible confindence level (e.g. 99%), and finally down to the horizontal axis to get the SMALLEST minimax slip-rate not violating these assumptions (about 12 mm/yr); hence, somewhere there is a patch on the SJF which is slipping at least this fast. All acceptible minimax slip-rates then exist in the pie shaped region not excluded by the hatchures.

E-3

Surface Deformation and Seismicity Compared in a Structural Context

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(914) 359-2900

Investigations

The broad-scale deformation elements of the master model can be inferred from analysis of VLBI, GPS and other geodetic data. But for making the connection between this broad-scale modeling and the actual behavior of faults, detailed near-fault studies will be required. How is interseismic deformation partitioned between elastic and recoverable strain, and permanent strain? Can geodetic measurements of deformation fields be reconciled with the deformation inferred from microseismicity and/or that inferred from geological structure? Can near-fault changes in stress orientation (inferred from seismicity and stress measurements) be recognised in geodetic data? Can combined studies of seismicity and near-fault geodesy give information about segmentation, block rotation, etc.? The greatest limitation on such studies at present is the lack of suitable geodetic data, and it is anticipated that SCEC will provide a substantial increase in such data in the years to come. We propose to use currently available geodetic data sets to make a start on these problems. We anticipate that we will be able both to make progress on the questions asked above, and to use our results to better plan future geodetic observations by SCEC.

We propose to quantitatively compare surface deformation from geodetic data (primarily from USGS trilateration networks, but also using recent GPS data) with seismic moment release from the USGS network in southern California. This comparison will be carried out upon the backdrop of the long-term deformation reflected in structure. The focus will not be on the co-seismic and post-seismic deformation associated with major earthquakes; we will be primarily concerned with interseismic deformation.

Results (October, 1991)

The trilateration data set for southern California has been obtained from USGS Menlo Park, and a "cleaned" version of a substantial subset of the data has been given to us by Hadley Johnson of IGPP, U.C. San Diego. Analysis of these data in the way described above has not yet begun; we anticipate working on the data after Christmas, once the first PI has completed a number of scheduled field experiments.

E-4

Progress Report to SCEC

Velocity Field in Southern California from GPS and VLBI

B. H. Hager, PI; T. A. Herring and R. E. Reilinger, co-I's
Massachusetts Institute of Technology, Cambridge, MA 02139
October 21, 1991

We proposed two projects directly related to SCEC goals: 1) to produce a map of the velocity field in southern California using all available GPS, VLBI and conventional data in the region, and 2) to interpret this velocity field using both "traditional" dislocation models of creep at depth on faults and more "realistic" models that include viscous relaxation in the intracrustal asthenosphere. Most of our effort to date has been directed at task 1).

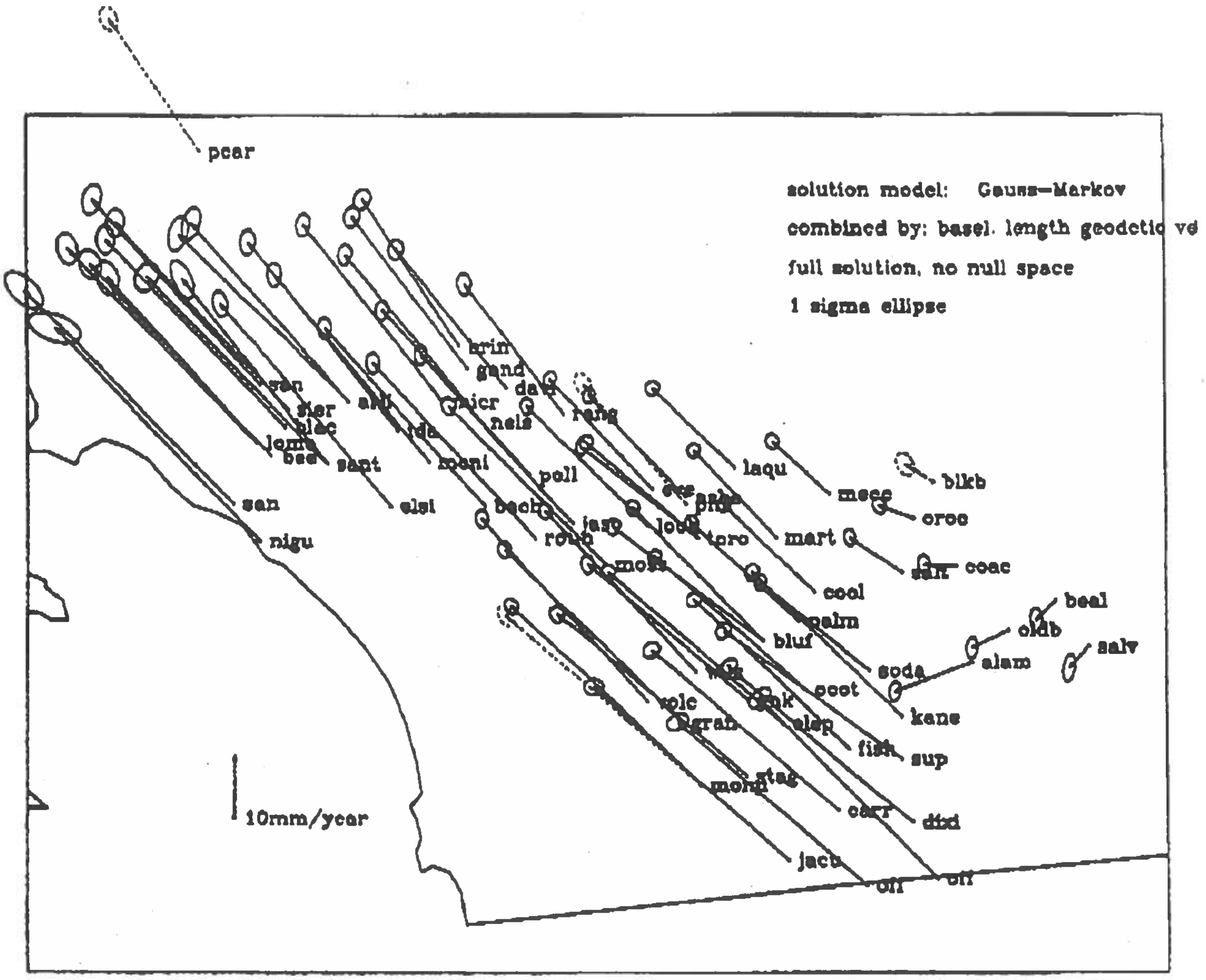
The velocity field from space geodesy is being estimated using Tom Herring's newly developed "Global" software, which uses a Kalman filter to combine station-position covariance matrices and estimates to form a single rigorous solution for positions and velocities. Up to now, we have concentrated on reanalyzing GPS data from two subsets of data - the "Trex" experiment (primarily funded by NSF) analyzed by Mark Murray at MIT for his Ph. D. thesis, and the Ventura Basin experiments, (primarily funded by NASA) analyzed by Andrea Donnellan of Caltech for her Ph. D. thesis. To strengthen the fiducial tracking network for this analysis we also used data from the 1988 Global Tracking Experiment (GOTEX); from the 1991 IERS GIG campaign; and recent data from the PGGA. In all, almost 200 GPS experiments were analyzed. Since the bulk of the data analysis for all these experiments was carried out at MIT, , it made sense to start work on these data sets. It surprised us how much work such a seemingly straightforward project turned out to be, requiring discovery of such pitfalls as non-standardized nomenclature for fiducial sites.

Danan Dong, the student supported by this grant, has made substantial progress, both theoretical and in the area of software development, in combining conventional and space geodetic survey data. His approach is to remedy the rank deficiencies of terrestrial geodetic data by using the coordinate and velocity information from the space geodetic solutions as the "model coordinates" in the inversion, or, alternatively, to use a Gauss-Markov approach. An example, using VLBI and trilateration in southernmost CA, is shown in the attached figure.

In terms of code development, our next step is to combine GPS and VLBI solutions. This is expected to be straightforward. We are also attempting to acquire all useful trilateration data, primarily from USGS, and triangulation data from NGS. We also need to acquire "clean" GPS data from SCEC.

Figure: Gauss-Markov solution for velocity field of southernmost CA obtained using the VLBI solutions at monu (Monument Peak), pinf (Pinyon Flats, assumed = asbe), blkb (Black Butte, assumed = oroc), and pear (Pearblossom, assumed = brin) combined with denser trilateration data.

E-5


pcar
solution model: Gauss-Markov
combined by: basel. length geodetic ve
full solution, no null space
1 sigma ellipse
brin
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rouo
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mart
salt
coac
mom
cool
palm
beal
oldb
salv
bluf
alam
soda
scot
kane
volc
grab
alep
fish
sup
stag
mond
carr
dixi
jacu
off
off
10mm/year

Report to SCEC for the October 1991 Workshop: Group E, #4 E-6

Geodetic Approach to Quantification of Earthquake Hazards in the Los Angeles Basin Within the Next 3 to 5 Years

Principal Investigator: Kerry E. Sieh
Co-Investigator: Kenneth W. Hudnut
Institution: Seismological Laboratory
California Institute of Technology

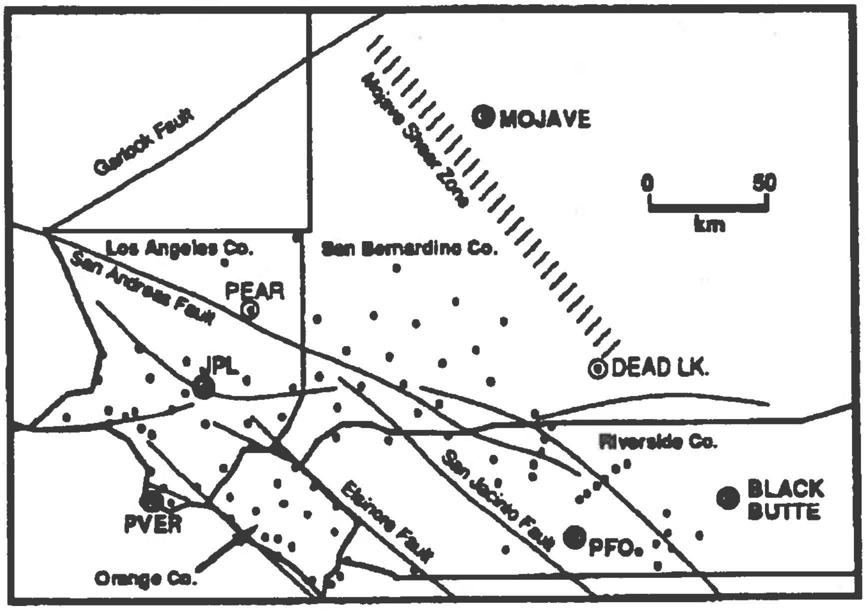
Using historical geodetic data and our GPS data from 1990 and 1991, we are working towards providing displacement results and to estimate earthquake hazards using SCEC funding to help support our data analysis, interpretation and modelling. Initial results from work in 1991 are still preliminary, but we plan to submit a paper on these results for publication during early 1992. Much of our effort in 1991 has necessarily been re-directed at studying displacements associated with the Sierra Madre earthquake in detail - these results of our SCEC work are to be presented at the Fall AGU meeting, and a preprint of that study will be ready at that time.

The purposes of this project, specifically related to earthquake hazards, are as follows: 1) assess overall slip distribution pattern and relate this to individual structures in the Los Angeles basin, 2) analyze for locked versus aseismically slipping portions of the detachment/ramp fault system (e.g., is the Santa Monica Mtns. fault-propagation fold accumulating stress interseismically?), 3) model and determine the interaction of the San Gabriel Mtns. thrust-sheet wedge with the San Andreas fault and determine how this interaction may affect recurrence interval modulation on the San Andreas fault. A first attempt at determining locked versus slipping patches will be done with simple dislocation modelling. In addition to these earthquake hazards goals, the following more general aims are being addressed by our study: 1) is fold development consistent with the kink-band model of Suppe, or another model?, 2) what role do left-lateral faults play in the LA Basin, and rigid-body block rotations occur in the San Gabriels or in the Fontana-Chino area?

This project is a major component of the geodesy group efforts toward the SCEC goal of assessing earthquake hazards in the Los Angeles Basin. Our contribution is presently in determining the spatial distribution of strain during the intervals 1933-1978, 1978-1990, and proposed work will include the 1990, 1991 and 1992 survey data comparisons and interpretation of those data. Currently, we use dislocation models, and with various possible geometries and slip patterns for buried and surficial faults in the study area.

We will soon complete our comparison of 1978 trilateration data to our 1990 GPS data (from a 23-station network across the LA Basin), and of the 1933 triangulation with these later surveys to specifically study strain across the San Fernando Valley. Our work may shed light on possible mechanisms for the substantially increased M>4.5 seismicity in this region since 1987, as discussed by Jones et al. (SCEC Bull. No. 1, 1991).

Caltech GPS Stations in Southern California



E-7

TECTONIC DEFORMATION IN SOUTHERN CALIFORNIA

DAVID D. JACKSON, DEPT EARTH & SPACE SCIENCES, UCLA

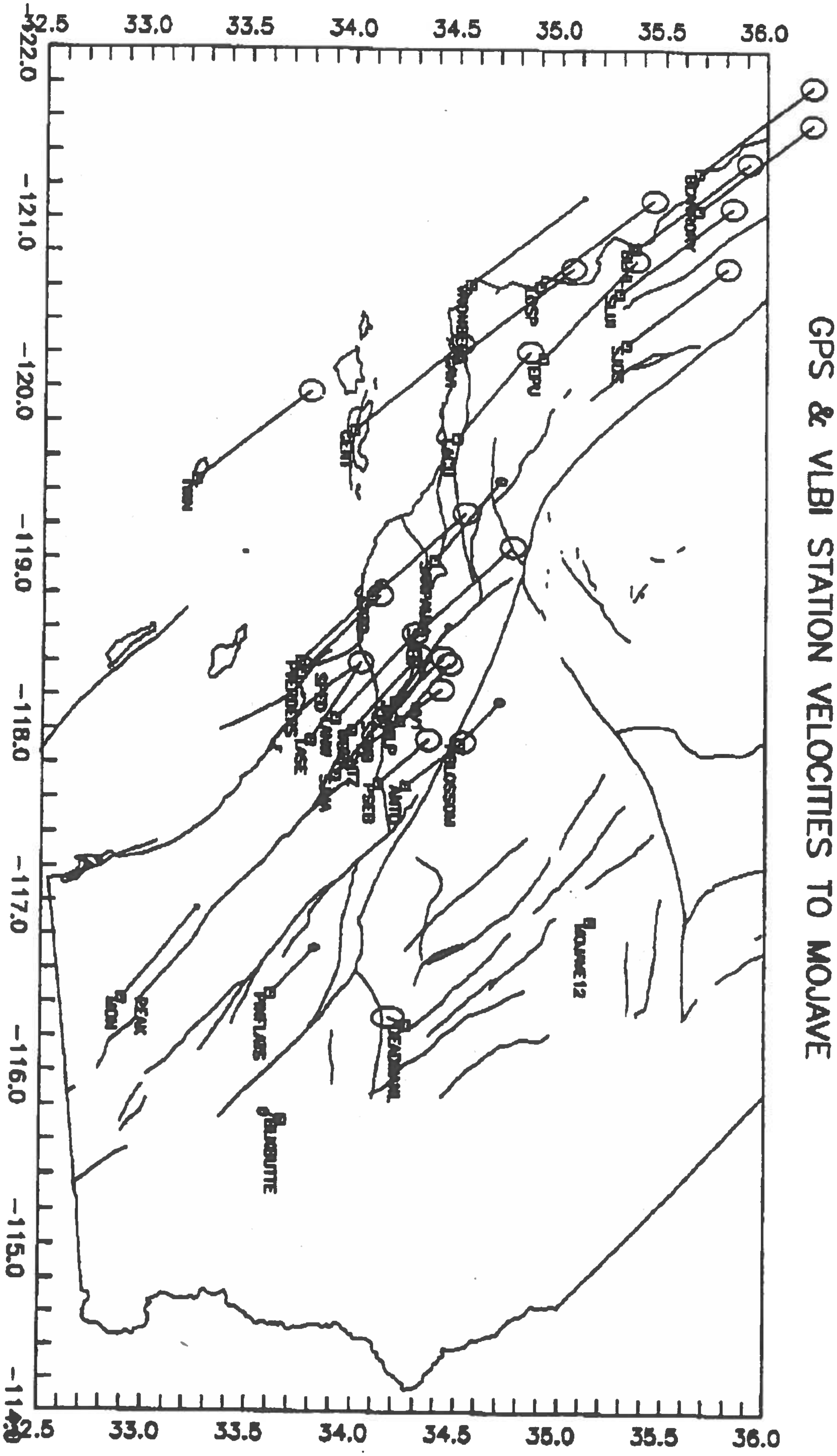
OCTOBER 24, 1991

We used a combination of VLBI, GPS, and triangulation data to construct a map of horizontal velocity of tectonic deformation in southern California. The map is shown in Figure 1. To construct the map, we started with Very Long Baseline Interferometry (VLBI) data, which are, on average, the most accurate geodetic data avaiable. These data then determined the velocity of points MOJAVE12, PVERDES, SANPAUL, PINFLATS, PBLOSSOM, JPL, DEADMANL, BLKBUTTE, MON PEAK, and VNDNBERG. We then measured the relative velocities of SAFE, CENT, TWIN, LACU, GAVI and WILP with repsect to PVERDES and VNDNBERG using measurements of relative position determined from Global Positioning System (GPS) data. Finally we used GPS combined with historic triangulation and trilateration to determine the remaining velocities. The velocity vectors show that VNDNBERG, CENT, TWIN, and most of the site along the coast north of latitude 35 are all moving at about 40 mm/yr relative to MOJAVE12; that is, they are on the Pacific plate. Within the Los Angeles basin we find N-S convergence of about 7 mm/yr, consistent with geological findings of the possibility of blind thrusts beneath the basin.

We used the data described above, as well as available data from the USGS trilateration networks, to determine the translation velocities and rotation rates of 12 crustal blocks, as shown in Figure 2. We allowed for creep on each fault, and we included the newly discovered Mojave Shear Zone as a fault. We also included as data the geologically measusred slip rates on faults, and limits on the convergence or dirergence of blocks. Results show good agreement with plate tectonic theory and all of the input data, implying that the deformation rates do not vary much over the relevant time scales (from a few years to a few thousand). The model shows significant deformation offshore south of Lat 34 (5-10 mm/yr between Palos Verdes and the Channel Islands), but no significant displacement on the Hosgri fault (0-5 mm/yr). The slip rate on the San Andreas at Wallace Creek is 33 + 3 mm/yr, agreening well with geological estimates. The good agreement obviates the need for time dependent strain rates (anelastic rheology), although it does not urle our anelastic stress relaxation at depth.

E-8

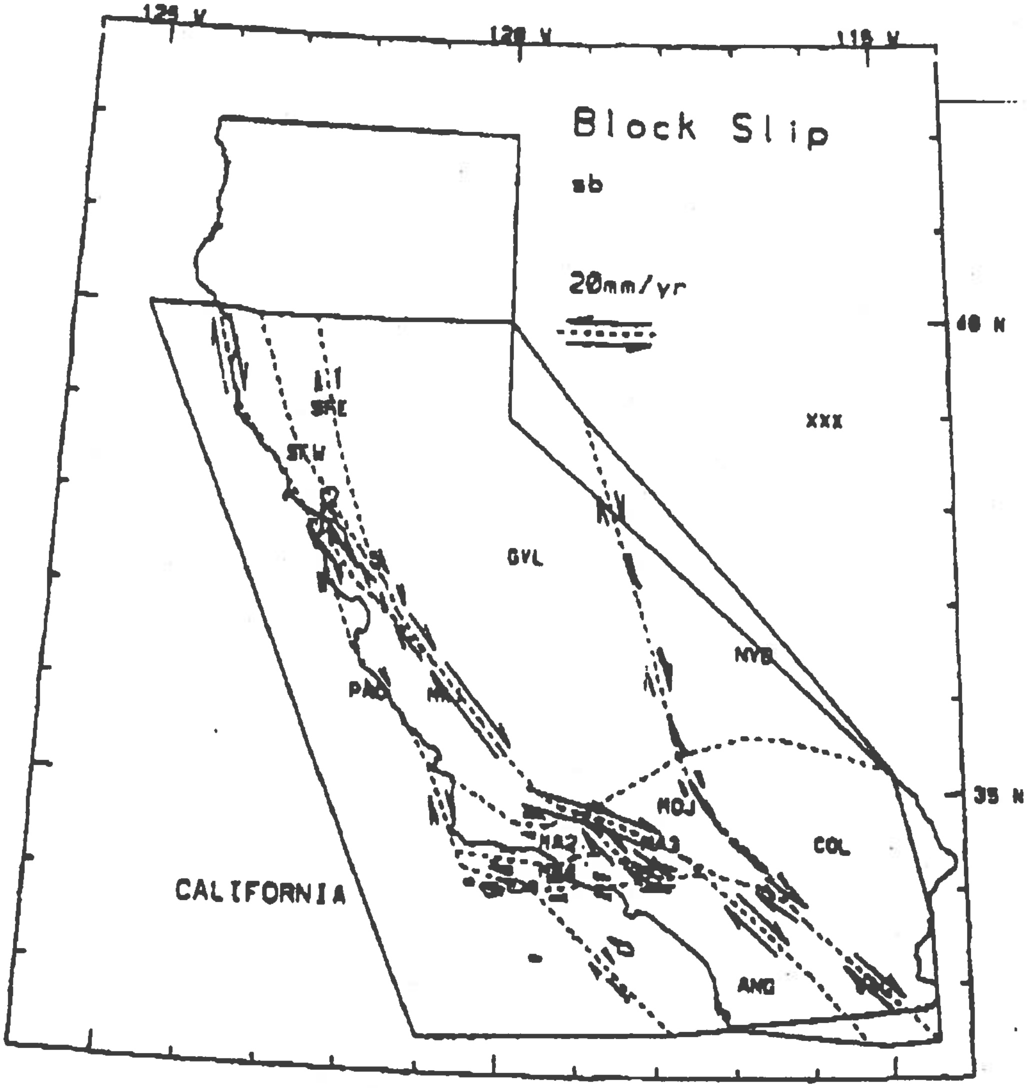
FIGURE 1



GPS & VLBI STATION VELOCITIES TO MOJAVE

E-9

FIGURE 2


124 W
120 W
116 W
40 N
35 N
Block Slip
sb
20mm/yr
XXX
SRE
SKW
GVL
NVB
PAC
MOJ
COL
MA2
MA3
ANG
CALIFORNIA

E-10

Annual Summary Report, Southern California Earthquake Center, USC P.O.#569928

Evaluation of the characteristic earthquake concept in Southern California

James R. Rice
Department of Earth and Planetary Sciences and Division of Applied Sciences
Harvard University, Cambridge, MA 02138
October 1991

Studies are underway on identifying possible physical origins of characteristic earthquake response and on examining limitations to the concept. These involve projects on the *physics of earthquake sources* and on *crustal deformation.*

Physics of earthquake sources. Strong geometrical variations such as jogs or stepovers at the ends of fault segments can lead to characteristic earthquake behavior, at least for a sequence of earthquakes. However, there is much current interest in the concept that essentially uniform fault models can lead to spatio-temporally complex slip response. We are studying such possibilities in a related USGS program, using models that properly incorporate 3D elastic interactions between slip and stress distributions and which use lab based rate- and state-dependent friction laws. Here we seek to understand whether uniform fault models which show spatio-temporally complex slip can be tripped into a characteristic earthquake mode by modest variations of frictional constitutive properties or geometry along strike.

The work accomplished so far on this topic has been on computational analysis of slip on a long vertical strike-slip fault between elastically deformable crustal blocks. These are driven such that each point on the fault moves, in long-term average, at an imposed "plate" velocity. The analysis is done by boundary integral equation methods based on the Chinnery solution. Rate- and state-dependent friction applies on the fault surface, and A–B [$=Vd\tau_{ss}(V)/dV$] varies with depth, in a way specifically constrained by data on granite under hydrothermal conditions, being negative in the cool/shallow crust and positive in hot/deeper regions (V=slip speed; τ_{ss}=steady state frictional strength). At each depth, constitutive properties in the models are either uniform in the along-strike direction or are perturbed, sometimes only slightly, from uniformity. Results thus far, from simulations with sufficiently refined grids to approach the continuum limit (which, unfortunately, means large and rather slow computations, and which constrains the range of characteristic slip distances for state transitions which can be studied), suggest that uniform fault models are remarkably resistant to breakup into spatially complex slip patterns along strike. This is in interesting contrast to the conclusions which other investigators have drawn based on inherently discrete models (such as cellular automata or spring-block arrays with simplified classical friction laws, which have no well defined continuum limit upon reduction of cell or grid size).

Only limited study of the response in the presence of significant property variations along strike has yet been done and conclusions on the topic are very tentative. Nevertheless, the results show the possibility that division of a long planar fault zone into segments along strike with differences in constitutive properties, that would be consistent with, say, a two or more variation in earthquake recurrence time (if the local properties applied everywhere), may lead to phase locking of the array of segments into coordinated earthquake response, with an intermediate recurrence interval, rather than to quasi-independent characteristic behavior of the segments. If this feature is found to be general in further study, there would seem to be a strong case for the necessity of geometric obstacles to slip transmission at segment ends as a basis for characteristic earthquake response.

Crustal deformation. The aim is to apply a physical model of crustal stressing and deformation, in the interseismic period, near a locked fault zone to examine time dependence in loading of a fault segment which, at least sometimes, responds in a characteristic-like earthquake mode. The focus in the first year is on the Parkfield segment. The SCEC funds are used to share the support of a postdoc, Y. Ben-Zion, who is studying similar issues under complementary support from an NSF/EAR grant. Crustal deformation is assumed to be driven by a steady underlying shear flow in the mantle, consistent with Pacific/N. America relative motion and uniform along strike over a length scale long compared to the Parkfield segment. The elastic-brittle crust is coupled to the mantle flow through a viscoelastic lower crust, of which properties are somewhat constrained by our previous modeling of SAF geodetic data, including that from the greater Palmdale network, in work by Li and Rice (JGR,'87) and Fares and Rice (EOS,'88). (Plausible ranges for relaxation properties in the lower crust may be somewhat further constrained by our ongoing USGS supported analysis of postseismic deformation following the 1989 Loma Prieta earthquake). In the simple modeling here, in contrast to that discussed on the previous page, the fault zone is divided into locked portions, on which slip is imposed kinematically at the times of prior earthquakes, and freely slipping parts; locations are constrained by seismicity. An important consequence of the model is that the loading rate, and hence seismic behavior, of a particular fault segment is to some extent affected by its neighbors; for Parkfield, these are the regions of the 1857 (and perhaps 1906) earthquake(s), and the creeping zone to the NW. Thus the loading rate of the Parkfield patch must inevitably have some time dependence, dictated by timing and postseismic effects of prior great earthquakes. Likewise, the NW end of the 1857 segment should be affected by Parkfield ruptures.

3D finite element calculations are employed to model such interactions. The model most extensively studied so far consists of a 17.5 km elastic upper crust, a 7.5 km viscoelastic lower crust, and a stiffer and more viscous viscoelastic upper mantle. The crust has a single vertical fault plane extending to the top of the mantle. That plane is locked against slip, except in great earthquakes, over the top 12.5 km in zones along strike corresponding to the 1857 and 1906 events. Free-slip boundary conditions are imposed on the fault plane below those locked rupture zones and everywhere in the creeping region between them. An imposed constant far-field shear motion at 35 mm/yr and periodic 1906- and 1857-type earthquakes generate slip rates along the creeping fault segment that show non-uniformity in time. Shortly after an adjacent great earthquake, slip rates in the creeping zone are higher than the far field velocity, while later in the cycle they are lower. If Parkfield earthquakes are a response to this time dependent loading, their recurrence interval would tend to lengthen with time since the 1857 event. Thus, an underlying hypothesis of characteristic periodic earthquakes at Parkfield may not provide the best estimate of the occurrence time of the next event. For example, using the statistics of past events we find that if Parkfield earthquakes are responses accumulated slip deficits near Middle Mountain, the next event would be predicted for about 1992 ± 9 yr if the lower crust relaxation time is 15 yr, and 1995 ± 11 yr for lower crust relaxation time 7.5 yr, rather then the 1988 ± 7 yr estimate based on periodicity in time. These relaxation times are consistent with the range, albeit poorly constrained, found in fitting other geodetic data along the San Andreas system, the range being about 1 to 2 yr per km of thickness assumed for the relaxing layer (only the ratio of relaxation time to layer thickness, and neither independently, is of significant influence on the time dependent surface straining predicted by models of the type examined).

Future extensions are envisioned to analyze interactions of other possibly characteristic fault segments with their neighbors.

E-12

Progress Report, October 1991: Marine Terraces and Earthquake Occurrence.

SCEC Working Groups: C (Fault Zone Geology) and E (Geodesy).

Steven Ward, Institute of Tectonics, University of California, Santa Cruz

Synthetic Seismicity. Most of my SCEC related research in the past seven months has been directed toward demonstrating how synthetic seismicity calculations, based on the concept of fault segmentation and incorporating the physics of faulting through static dislocation theory, can improve earthquake recurrence statistics and hone the probabilities of hazard. I have made substantial progress in this project as documented in two *Journal of Geophysical Research* papers, one accepted and one submitted. Compared to forecasts constructed from a hand full of earthquake recurrence intervals, forecasts constructed from synthetic seismicity (see Figure 1) are more robust in that they embody regional seismicity information over several units of magnitude, they can extrapolate seismicity to higher magnitudes than have actually been observed, and they are formulated from a catalog which can be extended as long as needed to be statistically significant. Synthetic seismicity models can also be used to judge the stability of common rate estimates and the appropriateness of idealisations to the earthquake cycle. I find that estimates of fault slip rate are unbiased regardless of sampling duration while, on the other hand, estimates of earthquake recurrence time are strongly biased. Recurrence intervals estimated from seismicity samples less than about ten times the actual recurrence interval will almost certainly be too short. For the Middle America Trench, it would take about 200 and 400 years of monitoring to constrain slip and recurrence rates to ±10%. Increasing gap time generally increases conditional probability of earthquake occurrence, but the effect is weak. For the MAT, the spread parameters of the best fitting lognormal or Weibull distributions (≈ 0.75) are much larger than the 0.21 intrinsic spread proposed in the Nishenko-Buland hypothesis (See Figure 2). Stress interaction between fault segments disrupts time or slip predictability and causes earthquake recurrence to be far more aperiodic than has been suggested. With the arrival of Dr. Barrientos, a SCEC visiting researcher, in January 1992, and continued funding, we intend to apply this technique to the San Andreas fault with an eye toward reviewing the conditional probabilities proposed by the Working Group on California Earthquake Prediction.

Ward, S. N., A Synthetic Seismicity Model for the Middle America Trench, *Jour. Geophys. Res.* (in press), 1991a.

Ward, S. N., An Application of Synthetic Seismicity Calculations in Earthquake Statistics: The Middle American Trench, *Jour. Geophys. Res.*, (submitted), 1991b.

Marine Terraces. Space geodesy tells us that ≈8 mm/y of roughly North-South motion is being accommodated between Palos Verdes and the base of the Transverse Ranges. The goal of this work is to employ geological and geomorphological data to isolate the fraction of this motion on some of the faults closest to the coast. I have recently met with Dr. Ken Lajoie of the USGS Menlo Park and have reviewed his substantial data set on the heights and ages of marine terraces around Palos Verdes and Huntington Mesa and other geological information on the dome structures further north and inland. Although I have not yet done so, I don't foresee too much difficulty in translating the terrace data, through dislocation modeling, into slip rates for the Palos Verdes, and possibly the Newport Inglewood, faults. Dr. Lajoie and I have discussed other data sets (i.e. Ventura anticline) and envision continuing the project into 1992. The arrival of Dr. Valensise, a SCEC visiting researcher, in January 1992, should certainly increase the pace on this aspect of the project.

E-13

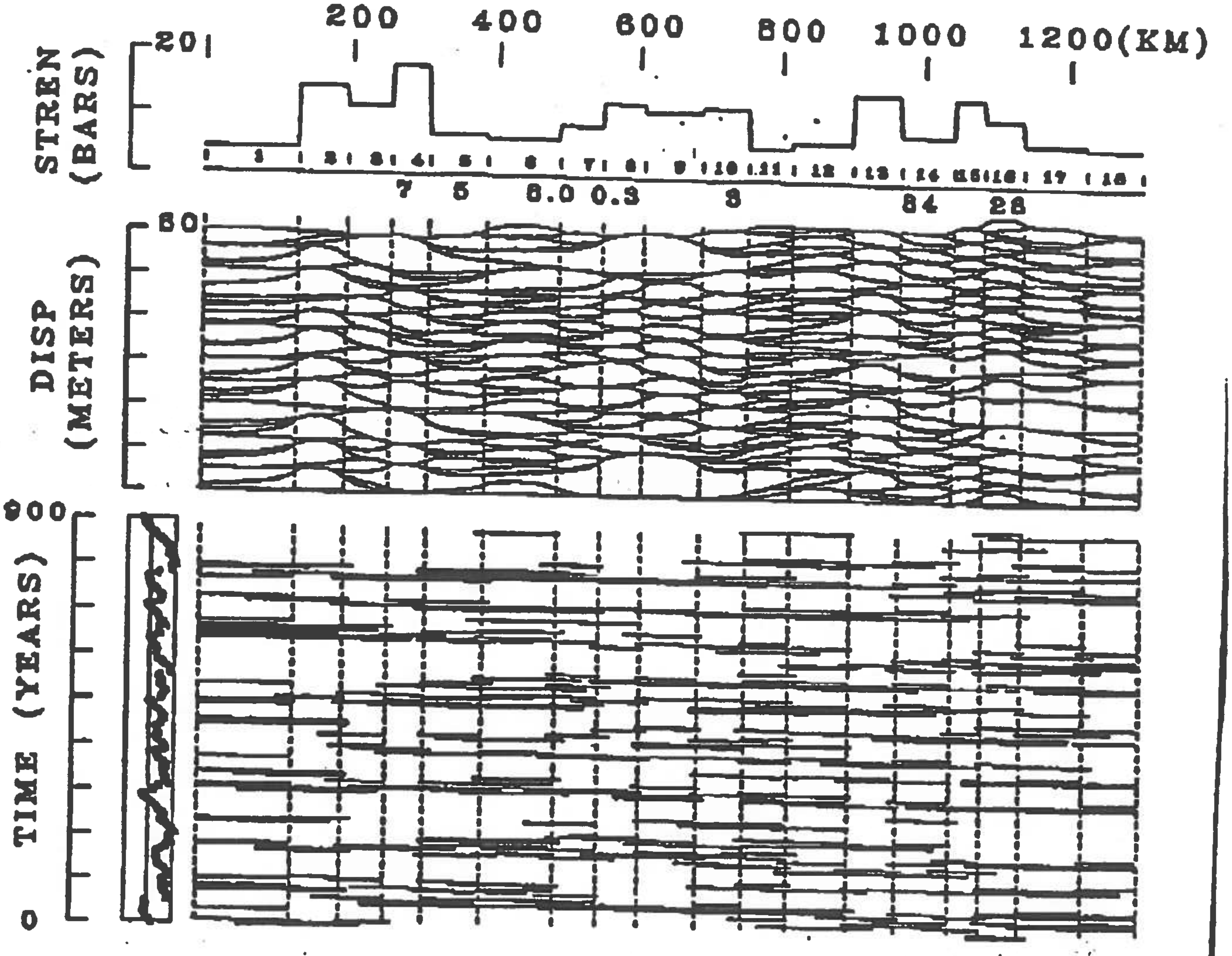


Fig. 1. Generic synthetic seismicity calculation for the Middle America Trench from *Ward* (1991a). *Top.* The sawtooth curve shows the distribution of segment lengths and strengths comprising this realization of the plate boundary. *Middle.* Accumulation of tectonic displacement along the 1300 km of fault strike. Each pillow represents the slip from an individual earthquake within the initial 900 years of a 4000 year run. *Bottom.* Space-time distribution of seismicity. Each horizontal line segment maps a $M \geq 7$ earthquake. Bold segments are $M \geq 8$ events. The statistics of recurrence of various size earthquakes within each segment is the prime concern of this work.

E-14

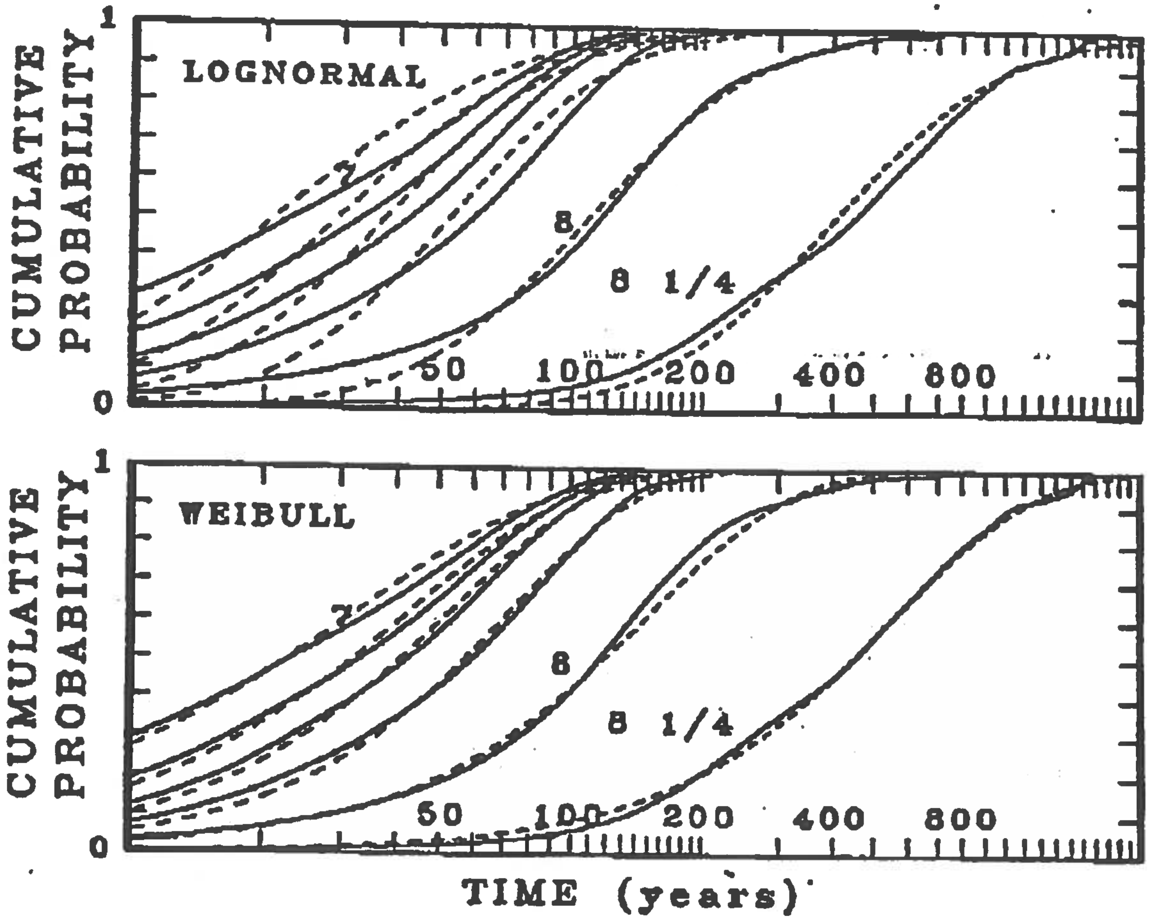


Fig. 2. Best fits of lognormal (*top*) and Weibull (*bottom*) distributions to the model MAT statistics. Each distribution was constrained to have the appropriate mean recurrence time. The remaining free parameter was searched for best fit at each M_o. The Weibull distribution better represents the statistics of recurrence than does a lognormal distribution. The spread parameters of the distributions are not constant, but generally decrease with magnitude. In all cases they are substantially larger than the intrinsic spread value of 0.21 proposed by *Nishenko* and *Buland* (1987). The larger spread reflects a higher degree of aperiodicity in the recurrence of major quakes.

E-15

PERMANENT GPS GEODETIC ARRAY OPERATIONS AT SIO (1991 SCEC ANNUAL REPORT)

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1. Introduction

The Permanent GPS Geodetic Array (PGGA) has been operated in California since the spring of 1990 by SIO and JPL with assistance from Caltech, MIT and UCLA. Funding for the maintenance of the network is provided by NASA and SCEC.. The goals of the PGGA are to monitor crustal deformation related to the earthquake cycle in California, continuously, in near real-time and with millimeter accuracy, using a fully automated and economically feasible system. The roles of the PGGA include providing reference sites and precise GPS orbital information to support detailed GPS geophysical surveys in California. For a more comprehensive overview of the PGGA please refer to the article "Continuous monitoring of crustal deformation" by the principal investigator in the June 1991 issue of GPS World.

2. Accomplishments

a) We have developed an automated system to collect, analyze and archive data from the PGGA sites at JPL, Piñon Flat Observatory (PFO), and SIO and from a globally distributed set of GPS tracking stations. We monitor data at a two minute sampling rate to all visible satellites, 24 hours a day, 7 days a week. All raw data in the SIO archive are translated into the Receiver Independent Exchange (RINEX) format for GPS data. These are archived on an optical storage device, the Epoch-1 Infinite Storage Server. All data collected to data are on-line and accessible via anonymous ftp. We have also archived the Caltrans California High Precision Network data collected from April to August 1991, the San Diego County High Precision Network collected in April 1991, and the GIG '91 data collected in January to February 1991.

b) Since September 1991, we have been generating a precise satellite ephemeris in support of GPS surveys in southern California. This orbit is available within one week of data collection. The time series of relative position for the JPL to SIO baseline using these orbits is shown in Figure 1. We are currently evaluating the orbits and estimate their precision to be at the 10-30 parts per billion level.

c) We monitored the position of the JPL site during the period of the Sierra Madre earthquake. We did not detect any significant motion at the several mm level in the horizontal and 10 mm level in the vertical. The time series of position of the baseline from Goldstone to JPL is shown in Figure 2.

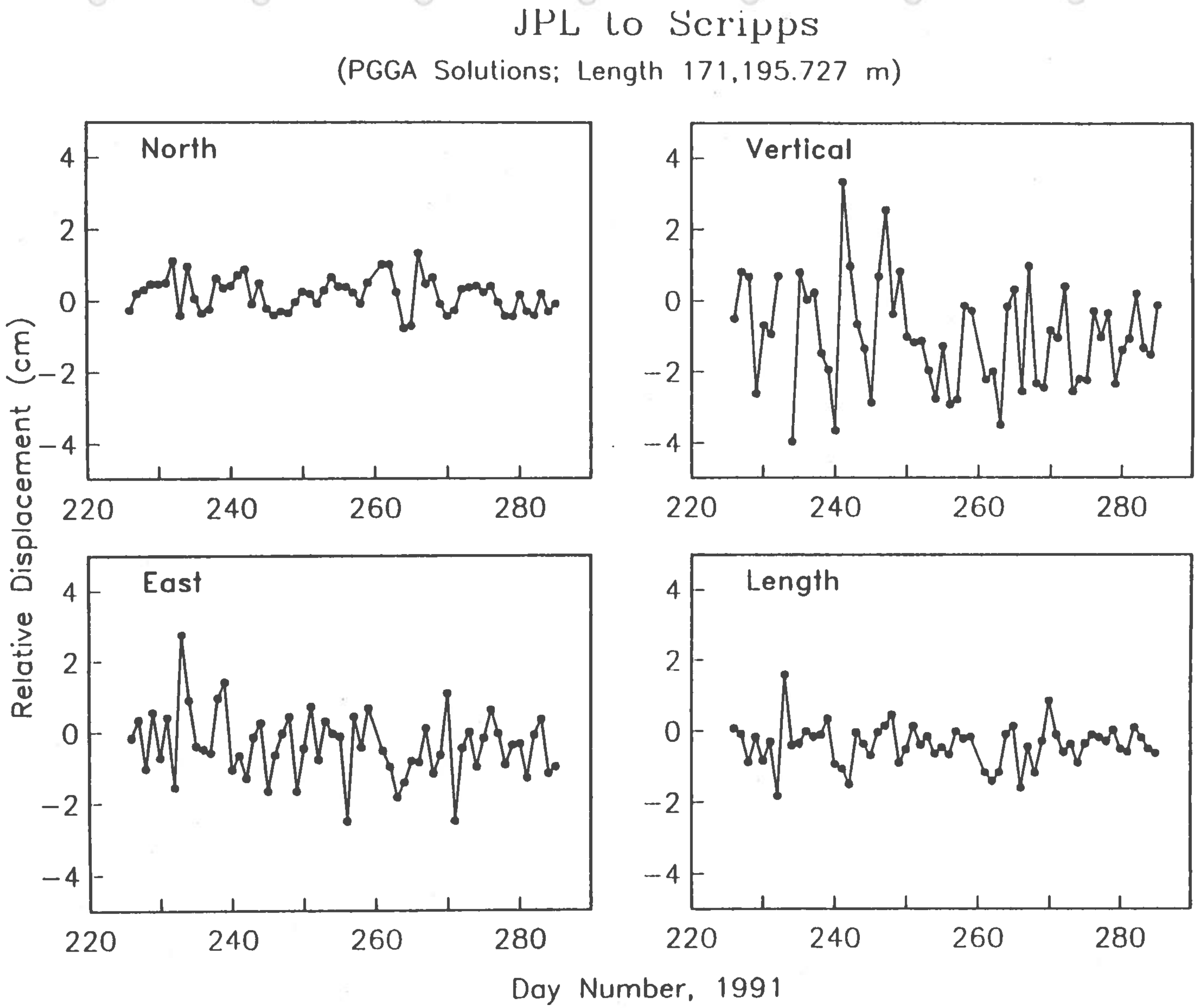
d) We are evaluating P-code receivers for possible purchase and deployment in the array. We have run zero and short baseline tests with the ROGUE SNR-8 and Ashtech P-code receivers and are preparing a report for the Crustal Deformation Committee.

e) We have hired Dr. Peng Fang to serve as the primary Network Data Analyst.

f) We have upgraded our computing facilities to streamline our automatic operations.

(g) We have made significant improvements to the GAMIT GPS software package in collaboration with MIT, and have instructed UCLA SCEC investigators in its operation.

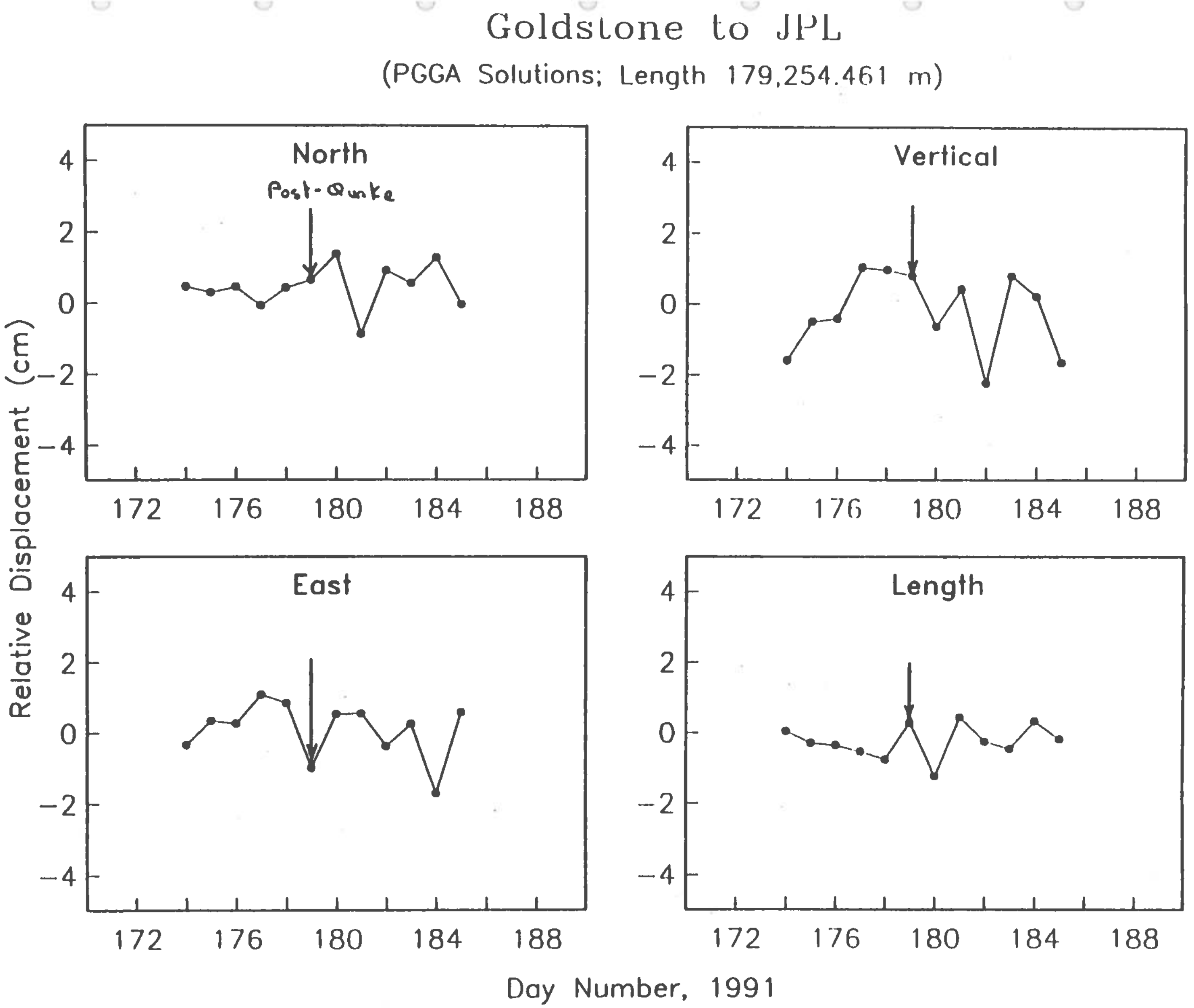
(h) A highly stable monument has been built at Vandenberg Air Force Base with funding from MIT. We plan to deploy receivers there and at Parkfield by December 1991, with assistance from JPL.



JPL to Scripps

(PGGA Solutions; Length 171,195.727 m)

1. Time series of position between the JPL and SIO PGGA sites. Each point represents a 24 hour solution.



Goldstone to JPL

(PGGA Solutions; Length 179,254.461 m)

2. Time series of position between Goldstone and JPL during the period of the Sierra Madre Earthquake. The vertical arrow indicates the first point after the earthquake (day 179). We detect no significant motion of the JPL site in Pasadena.

Mechanics of Blind Thrust Faults in the Los Angeles Basin

E-18

1991 Annual Report to the Southern California Earthquake Center*

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Goals and Objectives. Geodetic and geological evidence has revealed that the crust beneath the Los Angeles basin is contracting at a rate of 3-15 mm/yr in a north-south direction, and that a suite of blind reverse and thrust faults underlies the basin to accommodate this contraction. We seek to understand the deep fault geometry in the Los Angeles basin, to deduce or constrain the fault slip rates and, where possible, earthquake repeat times. In addition, we seek to understand the earthquake cycle on the blind faults, and to learn how adjacent blind faults interact as they are stressed and relaxed during the cycle.

Our first step was a systematic review of blind earthquake rupture and blind fault structures in southern California. The review was aimed at honing our modeling efforts to fault geometries, crustal rheologies, and earthquake sources appropriate for southern California. Seismic, geologic and geodetic data from the Los Angeles basin played a key role, as well as observations from other fold and thrust belts where the earthquake or seismic reflection record is superior to southern California.

Following the review, we began a set of numerical experiments on simple, isolated blind faults. Thus far we have pursued four broad lines of inquiry, all designed to probe the strain and displacement field associated with slip on blind faults, which we describe and illustrate briefly here:

Boundary Conditions. Here we considered the remote tractions and fault slip distribution best suited to reproduce patterns of observed geodetic contraction across the basin, coseismic surface displacement, and inferred earthquake stress drop. This led to a study of the strain field produced by *uniform slip*, in which slip is constant along the fault, and by *tapered slip* of the same mean value, but with an elliptical distribution that minimizes the stress intensity factors at the fault tips. Although the ground surface displacement for these two end members are similar (they are indistinguishable for blind faults), the strain fields at depth are quite different. We illustrate this result in Figure 1, for a reverse fault that cuts the earth's surface. Because remote basin contraction will produce tapered slip on freely slipping faults, and because tapered slip minimizes the artificially high strains at the fault ends, we elected to use tapered slip for the remaining studies.

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†Center Visiting Fellow, 1991-92

*Deformation Group

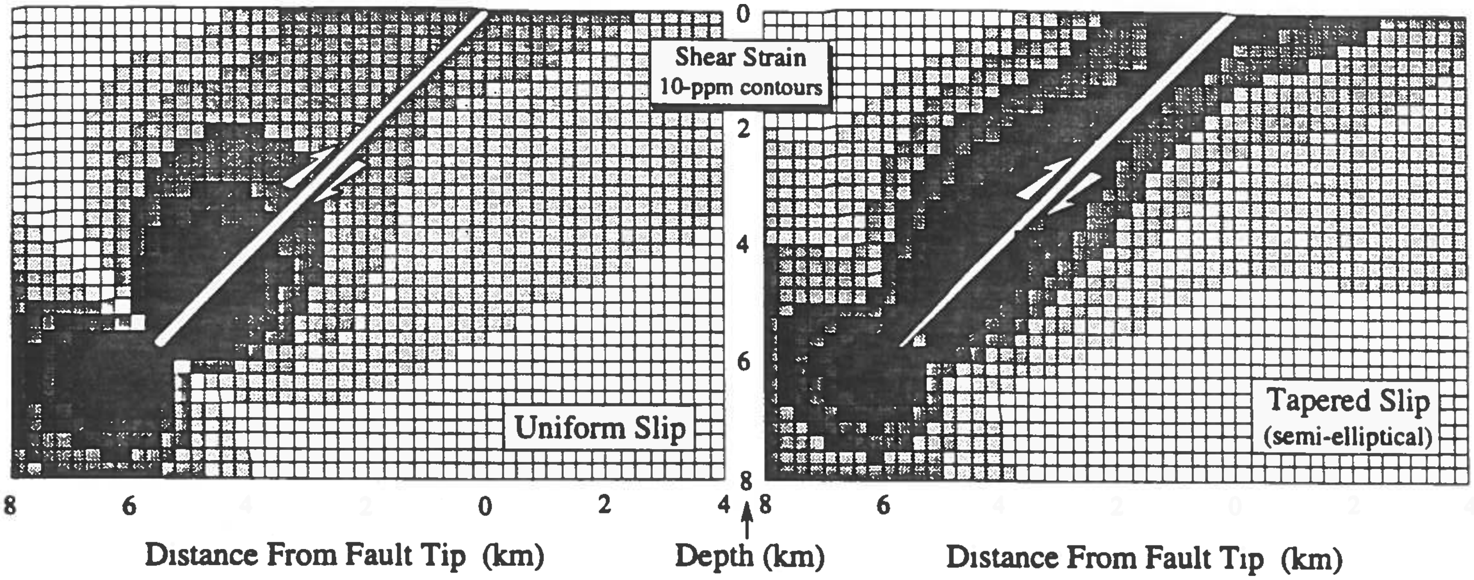

Fig. 1. Boundary-element visualizations of the strain-change produced by faults in an elastic halfspace; fault length along strike is infinite; fault width, W, is 8 km. The mean fault slip is 1 m, and thus the strain drop, u/W, is 125 ppm. The deviatoric shear strain is plotted, or the shear-strain maxima independent of orientation, $[\varepsilon_{12}^2+{}^1/_4(\varepsilon_{11}-\varepsilon_{22})^2]^{1/2}$ where the unit vector $\imath$ is horizontal and 2 is vertical; nodes are 0.5 km apart. Maximum strain plotted (black) is >50 ppm or 40% of the strain drop. For uniform slip, shear strain is concentrated at the base of the fault and diminishes toward the ground surface. For tapered slip, shear strain diminishes little toward the surface. In both cases, high shear strain extends farthest from the fault trace on the downthrown block (right side of fault).

Coseismic Strain Field at Depth. Here we investigated the shear and dilatation fields associated with tapered slip on blind faults, since patterns of aftershocks furnish a means to test whether the predicted strain changes are observed in the earth. We examined a suite of fault geometries that are found or are believed to exist in the Los Angeles basin, studying the effects of fault dip and the proximity of the fault to the free surface. We found that when D/W (the depth of the fault tip, D, divided by the fault's down-dip width, W) <1, ground-surface interaction significantly modifies the shear and dilatant strain fields. When D/W>>1, a high shear strain halo encircles the fault, with slightly concentrated strain at the fault ends. As the fault approaches the free surface, however, the halo breaks up into several isolated zones of high shear strain (Figure 2, left panel). These zones correspond to sites of high-angle reverse faults and aftershocks found in the cores of many active anticlines, which lie above the fault tip. The antisymmetric dipole pattern of dilatant strain that prevails when D/W>>1 is also disrupted as the fault nears the free surface, with the contraction lobe (-) above the fault tip becoming dilatant (+) (Figure 2, right panel). This site also corresponds to the region of secondary faulting and oil storage in anticlines lying above reverse faults. If the rocks at this shallow depth are strong enough to store elastic strain, the combined effect of increased shear and dilatation promote secondary failure.

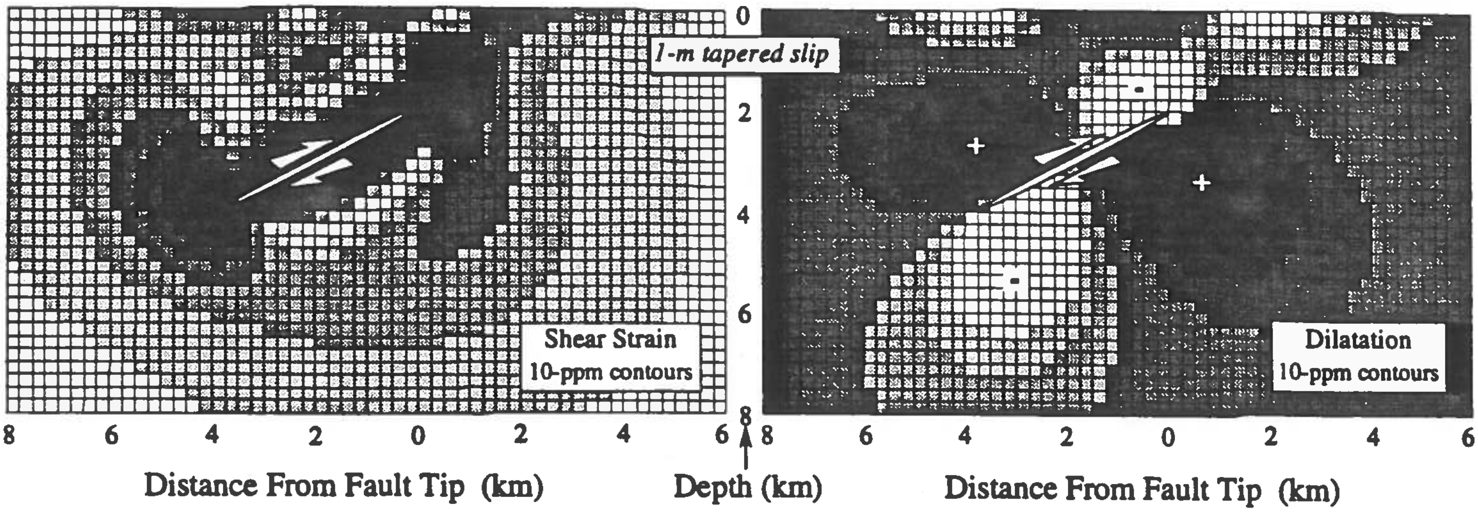

Fig. 2. Strain Field produced by 1 m of tapered slip on a 4-km-wide thrust fault dipping 25°. Coseismic strain drop is 250 ppm. Maximum shear strain shown is >50 ppm or 20% of the strain drop. Peak dilatant strains plotted (black and white fields) are >±30 ppm; neutral grey is <±10 ppm. Note that the nearly symmetrical pattern of strain below the fault is disrupted by the presence of the free surface above the fault.

Long-term Deformation and Strain. We are exploring several ways to reproduce the long-term evolution of structures associated with blind faults, with the goal of linking their coseismic deformation to the geological deformation, with kilometers of cumulative slip through repeated earthquakes. We have tested a two-modulus-region model in which both regions are elastic but one has a lower stiffness. The boundary between the regions can take any form, and thus can reproduce the Los Angeles basin configuration in 2 dimensions, with a basin of compliant sediments overlying stiffer basement rocks, in which faulting can take place in one or both regions. We have tested and successfully used this to simulate the modulus structure at the sites of the Coalinga and Loma Prieta earthquakes, where the seismic velocity structure is better known than in the Los Angeles basin.

The second mechanical model we are evaluating is one in which an elastic layer overlies an inviscid fluid, in which gravitational forces are balanced and the effects of erosion and deposition are included. Thus far we have tested surface-cutting reverse faults only. Finally, we are examining the deformation field for blind faults in an elastic incompressible solid (*eg.*, Poisson's ratio, $\nu=0.5$). Implicit in the methodology of balanced, retro-deformable cross-sections is the rule that cross-sectional area is preserved. In an incompressible solid, the dilatant strains are everywhere zero, so this rule is satisfied exactly (Figure 3). In practice, such a criteria means that mineral transport (dissolution, migration and precipitation) must occur on a more local scale for an incompressible solid than for a Poisson solid (where $\nu=0.25$), since there are no large-scale pressure gradients to drive the migration. The shear strain field for an incompressible elastic solid is similar to that for the Poisson solid, except that the deviatoric shear strains are uniformly higher.

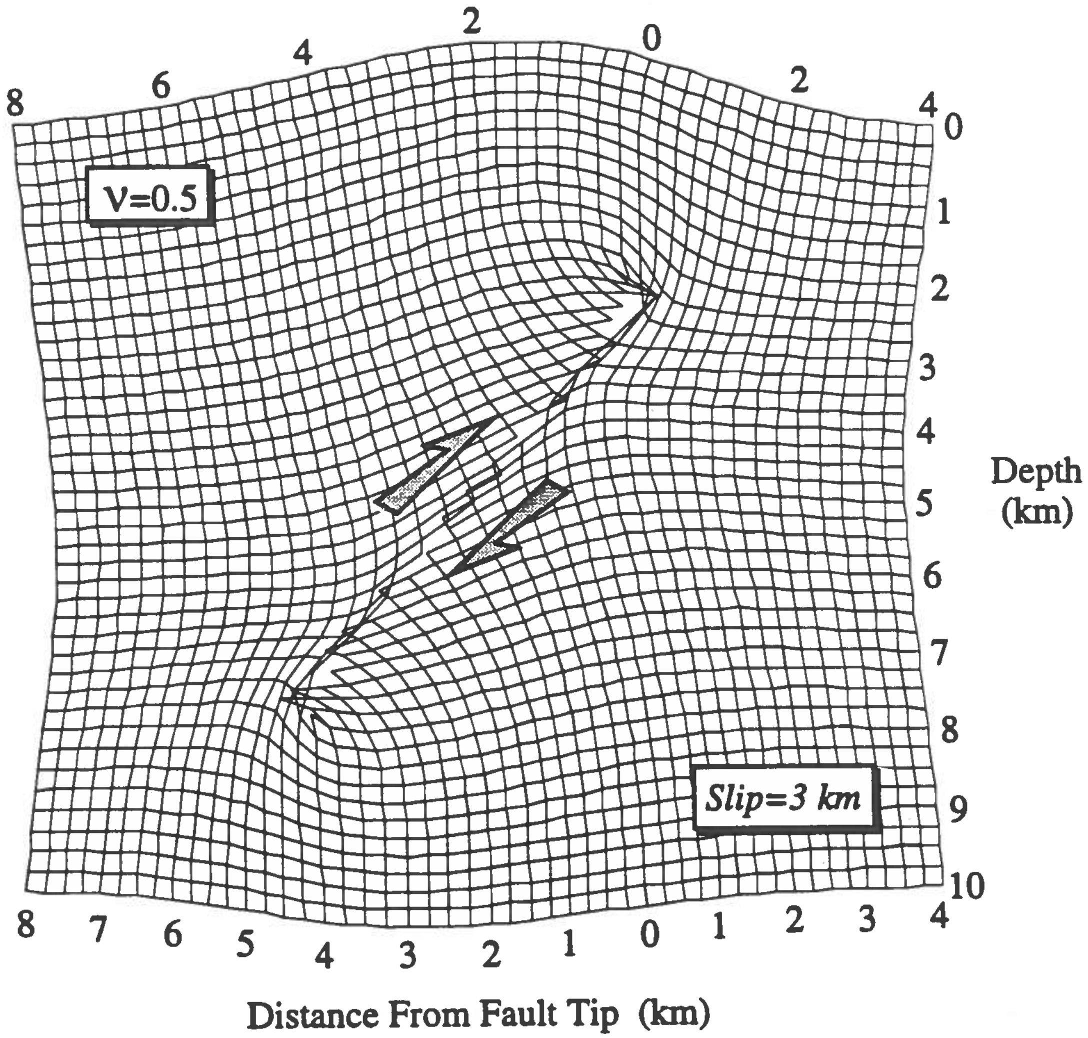

Fig. 3. Displacement field for a 6-km-wide reverse fault dipping 45°, buried at 3 km depth in an incompressible elastic halfspace. Tapered slip of 3 km is imposed on the fault, equivalent to a regional horizontal contraction of 4.24 km. An anticline is seen to form above the tip of the fault, in the same position as anticlines are observed in the field. The fault faces do not overlap, as they would for a Poisson solid.

Next Steps. For coseismic models, we have restricted ourselves to models with 1 m of mean slip, *u*. We plan to explore alternative slip normalizations, such as constant strain drop, *u*/W, and constant seismic moment, *u*W. We will also compare blind earthquake aftershocks and focal mechanisms with these results. We also plan to study the strain field associated with ramp-decollement and adjacent parallel faults, and to examine slip lines and strain rosettes to investigate preferred fault orientations and interactions.

For the long-term models, we will continue studying incompressible solids. We will also study zones of plastic yielding, such as the fault tip or fault bends, and carry out additional experiments with an elastic layer over an inviscid substrate. Finally, we intend to study the pattern of surface deformation produced by slip on the blind faults so that the Center's GPS network in the Los Angeles Basin will be optimized to detect slip on these faults.

<u>Group F: Regional Seismicity</u>

<u>Group Leader: Egill Hauksson</u>

F-1

SUMMARY REPORT: REGIONAL SEISMICITY (GROUP F)

Report assembled by Egill Hauksson from contributions by PIs.; 11 September 1991

The objectives of group F are to synthesize existing earthquake data and to develop new techniques for analysis of onscale broad-band data from southern California.

Project 1
Towards, real-time, routine broad-band seismology
E. Hauksson, H. Kanamori, and D. Helmberger
Caltech

Investigations

The goal of this project is to establish rapid data analysis methods for data from the TERRAscope broad-band seismic network.

Results

The Sierra Madre earthquake of 28 June 1991 provided a realistic test for our ongoing software development. This is the first major event that was recorded onscale with as many as six TERRAscope stations. The data were quickly retrieved via the Caltech gopher dial-up system at Pasadena. To obtain quantitative information on the earthquake as quickly as possible, we determined, peak ground acceleration, local magnitude, energy magnitude, seismic moment, and focal mechanism. In addition to developing new software, the software used for the Sierra Madre earthquake is being automated for routine use.

As a part of our contribution to the master model, we have started a project called: *Earthquake Atlas for Southern California*. The goal of this project is to present existing earthquake data in various formats to make them more useful to the end user. As a first step a paper presenting the last 13 years of seismicity has been written for the Engineering Geologists in southern California.

Publications

Hauksson, E.,K. Hutton,K. Douglass, and L. Jones, Earthquake Atlas for Southern California, 1978 1990, submitted to: Engineering Geology of southern California, 1991.

Kanamori, H , E. Hauksson, and T. Heaton, Experiment Toward Realtime Seismology Using TERRAscope ---1991 Sierra Madre Earthquake----, (abstract) submitted to fall AGU meeting 1991

F-2

PIs Egill Hauksson, Hiroo Kanamori, and Don Helmberger

Institution: California Institute of Technology

Title: Towards, Real-time, Routine Broad-band Seismology

A SCEC Project: Goals and Progress Report, 11 Sept. 1991

INVESTIGATIONS

The goal of this project is to establish rapid data analysis methods for data from the TERRAscope broad-band seismic network.

RESULTS

The Sierra Madre earthquake of 28 June 1991 provided a realistic test for our ongoing software development.

The six TERRAscope stations, PAS, GSC, PFO, SBC, ISA, and SVD recorded on scale the M_L=5.8 Sierra Madre earthquake of 6/28/1991 (34°15.7'N; 118°0.1'W). The data were quickly retrieved via the Caltech gopher dial-up system at Pasadena. This is the first major event that was recorded with as many as six TERRAscope stations.

To obtain quantitative information on the earthquake as quickly as possible, we performed the following analyses within the first two hours after the occurrence: 1) determination of the maximum acceleration at Pasadena (7% of g); 2) determination of M_L and the radiated energy; 3) determination of the focal mechanism and the seismic moment using the records from PAS and SVD. Although some minor changes were made for some of the parameters later, the results of these quick determinations proved good enough to be used for emergency services. The uniform instrumentation and software implementation greatly facilitated the timely use of TERRAscope data for the Sierra Madre earthquake.

The short duration of the SH pulse at Pasadena and the large energy-moment ratio for this earthquake indicate that the Sierra Madre earthquake is similar to the 1988 Pasadena earthquake and the 1989 Montebello earthquake, and belongs to a group of "high-stress-drop" earthquakes.

Presently, we are implementing software to determine local and energy magnitude, seismic moment, and focal mechanism automatically using the data collected by the Caltech Gopher. These results should be available within 30 to 60 minutes of the occurrence of significant earthquakes.

F-3

As a part of our contribution to the master model, we have started a project called: *Earthquake Atlas for Southern California*. The goal of this project is to present existing earthquake data in various formats to make them more useful to the end user. As a first step a paper presenting the last 13 years of seismicity has been written for the Engineering Geologists in southern California.

Publications

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Kanamori, H , E. Hauksson, and T. Heaton, Experiment Toward Realtime Seismology Using TERRAscope ---1991 Sierra Madre Earthquake----, (abstract) submitted to fall AGU meeting 1991

F-4

Report on Shear Wave Splitting in the Los Angeles Basin

Yong-Gang Li, USC, Group F (Regional Seismology) of SCEC

We are systematically examining 3-component seismograms recorded by USC Los Angeles basin seismic network (LABSNET) for evidence of shear-wave splitting in this active tectonic region. We have obtained the following results:

(1) A multi-station array (SCS) installed at the northern margin of the Los Angeles basin (on the USC campus) has recorded ~60 events within the shear-wave window during last three years. 3-component data show shear-wave splitting (i.e. Figure 1) with the leading shear wave polarized in N-S±15° independent of the location of events (Figure 2).

(2) Shear-wave splitting with 10-130 ms difference in traveltimes between the two split shear waves has been observed from events occurring at the depths of 6-18 km in the crystalline basement beneath the Los Angeles basin. The time delay of the slow shear wave increases as the travel distance in the basement increases.

(3) The observed shear-wave splitting is interpreted in terms of anisotropic crustal basement that contains vertical microcracks in the seismogenic layer beneath the Los Angeles basin. Shear-wave splitting may be due to a preferential alignment of microcracks under the present regional N-S compressional stress regime. Ray tracing for the anisotropic medium containing aligned cracks is used to fit shear-wave splitting data and yields an average crack density of 0.04 in the basement rock beneath the Los Angeles basin.

(4) 3-component data obtained from the borehole station DHB at depth of 1500m near the north end of the Newport-Inglewood fault (INF) also show shear-wave splitting but with the leading shear wave polarized parallel to the NW fault trace. Ray tracing yields 0.06 of crack density at the northern part of the NIF.

(5) 3-component data recorded by station GFP located on basement outcropping in the Santa Monica Mountains show complicate shear-wave splitting. For those events having near-vertical raypath, there is, in general, no shear-wave splitting observed. For events with large epicenters show that the polarizations of leading shear waves traveling from various directions have a scattered pattern, suggesting that microcracks within the reverse-fault controlled region may change the crack normal from horizontal to vertical.

(6) We examined whether there is probable temporal variation of shear-wave splitting observed at station SCS related to the major earthquakes in the area of interest during last three years. We did not find significant variation in time delay of the slow shear wave before and after three M>5 remote earthquakes. They are the M5.0 Pasadena earthquake (P) on Dec. 3, 1988, 22 km NE of SCS, M5.5 Upland earthquake (U) on Feb. 28, 1990 62 km ENE of SCS and M5.8 Sierra Madre earthquake (SM) on June 28, 1991, 42 km NNE of SCS. But, we found that the time delay varied before and after the M4.4 and 4.1 Montebello double earthquakes (MD) occurring on June 12, 1989, 10 km east of SCS. The delay time increased by a factor of ~1.5 before and during the double main shocks and abruptly decrease by a factor of 3 after the main shock. The delay time then gradually increased to the initial value after several months. We also found that the ratio of t_s to t_p varied before and after the Montebello main shock. t_s/t_p ratio decreased from the initial value of 1.74 to 1.66 when the double main shock occurred and abruptly increased to 1.77 after the event. The ratio then returned to the initial value after several months. The observed temporal variation in both time delay and t_s/t_p ratio from events of the MD sequence suggest that dilatancy might occur in the rock around the focal zone before a major earthquake. Because there were no three-component station close to focal zones of the other three M>5.0 major earthquakes (P, U and SM) in this time period, we could not obtained evidence for the temporal variation in shear-wave splitting related to them.

F-5

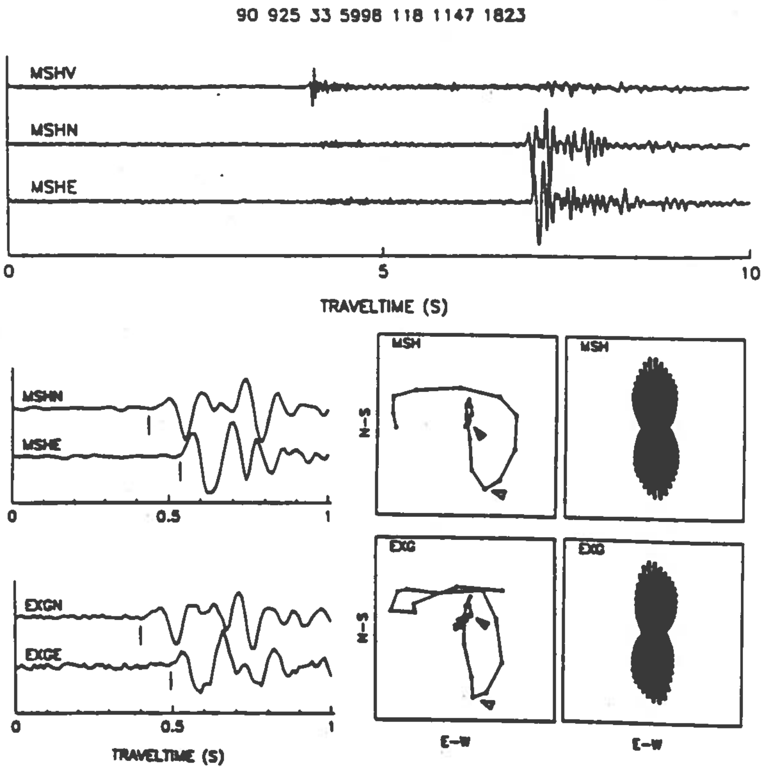

Figure 1 An example of shear-wave splitting observed for an event occurring at the depth of 18 km beneath the Los Angeles basin with epicenter 8.9 km east of SCS station array installed in the USC campus. Top: 3-component seismograms recorded by station MSH. Bottom Left: Time-extended seismograms of horizontal components from stations MSH and EXG. Arrivals of split shear waves are aligned by two vertical short lines, respectively. Bottom Mid: The corresponding horizontal polarization diagrams. The onsets of the leading and slow shear waves are pointed by a filled triangle and by an open triangle, respectively. Bottom Right: Aspect ratio diagrams for the two horizontal components from stations MSH and EXG. The maximum aspect ratio represented by a bar having the maximum length indicates the direction of the maximum principal stress.

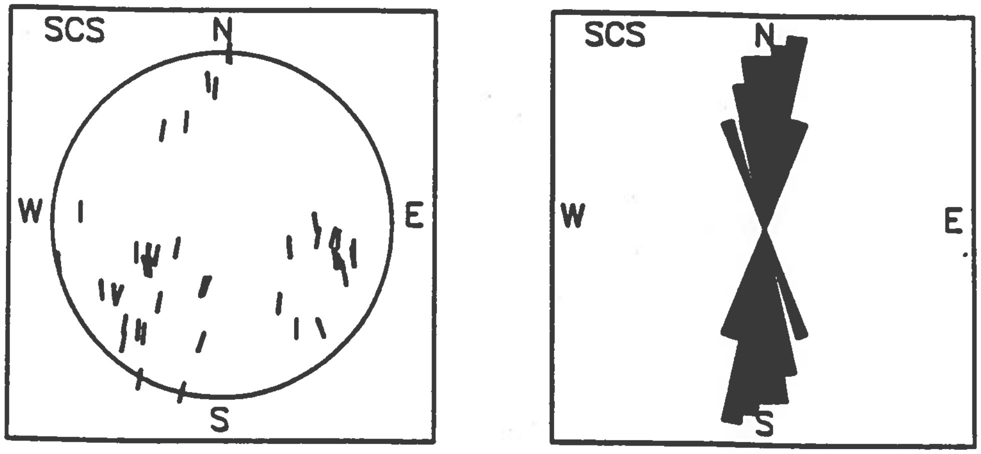

Figure 2 Left: Horizontal projections of the polarizations of the leading shear waves from fifty events within the shear-wave window of the five-station array SCS at the USC campus are shown in equal-area projections of the lower hemisphere of directions out of 55°. Right: Equal-area rose diagrams of the distributions of polarization directions of leading shear waves from fifty events used in the left panel. The centre of each panel corresponds to the station location.

F-6

Seismicity Studies in Southern California Associated with the San Andreas Fault System

NSF-USC PO# 572726

Craig Nicholson
Institute for Crustal Studies, University of California
Santa Barbara, California 93106–1100

ANNUAL PROGRESS REPORT

Funding for this project was received 8 May 1991. Due to prior commitments, work did not begin on this project until 15 September 1991; this report documents progress through 15 October 1991.

1) Revision of a manuscript on the seismotectonics of the Northern Elsinore fault zone, southern California, was completed [*Hull and Nicholson,* 1991]. Based on geological, seismological and other geophysical evidence, the northern Elsinore fault zone appears to be relatively young (~2.5 Ma), has accommodated only a small amount of cumulative horizontal offset (~15 km), and exhibits oblique-slip along discontinuous, non-vertical and possibly curvilinear fault segments. Microearthquakes both on and off the active fault segments exhibit similar oblique-slip focal mechanisms (Figure 1) and suggest that the axis of maximum horizontal compression (σ_1) of the regional stress field is oriented about 45°–55° from the general strike of the active Elsinore fault.

2) A preliminary high-resolution tomographic inversion of P-arrival times in the vicinity of the 1986 North Palm Springs (NPS) earthquake along the southern San Andreas fault has been completed and submitted for publication [*Nicholson and Lees,* 1991]. The preliminary tomographic images of 3-D velocity perturbations within the northern Coachella Valley reveal high-velocity anomalies along the fault that correlate with most of seismic slip during the NPS mainshock [*Hartzell,* 1989] and most of the aftershock hypocenters [*Nicholson et al.,* 1986], which suggests that the distribution of high-velocity anomalies may outline the asperity responsible for the earthquake (Figures 2 and 3).

3) Databases of earthquake arrival times from the Southern California Regional Seismographic Network (SCSN) along segments of the southern San Andreas and northern San Jacinto faults have begun to be organized for re-analysis. A major purpose of this study is to evaluate the degree of systematic mislocation that may be present in the current SCSN catalog of earthquake hypocenters and to determine the correct orientation, geometry, and style of deformation along active subsurface faults.

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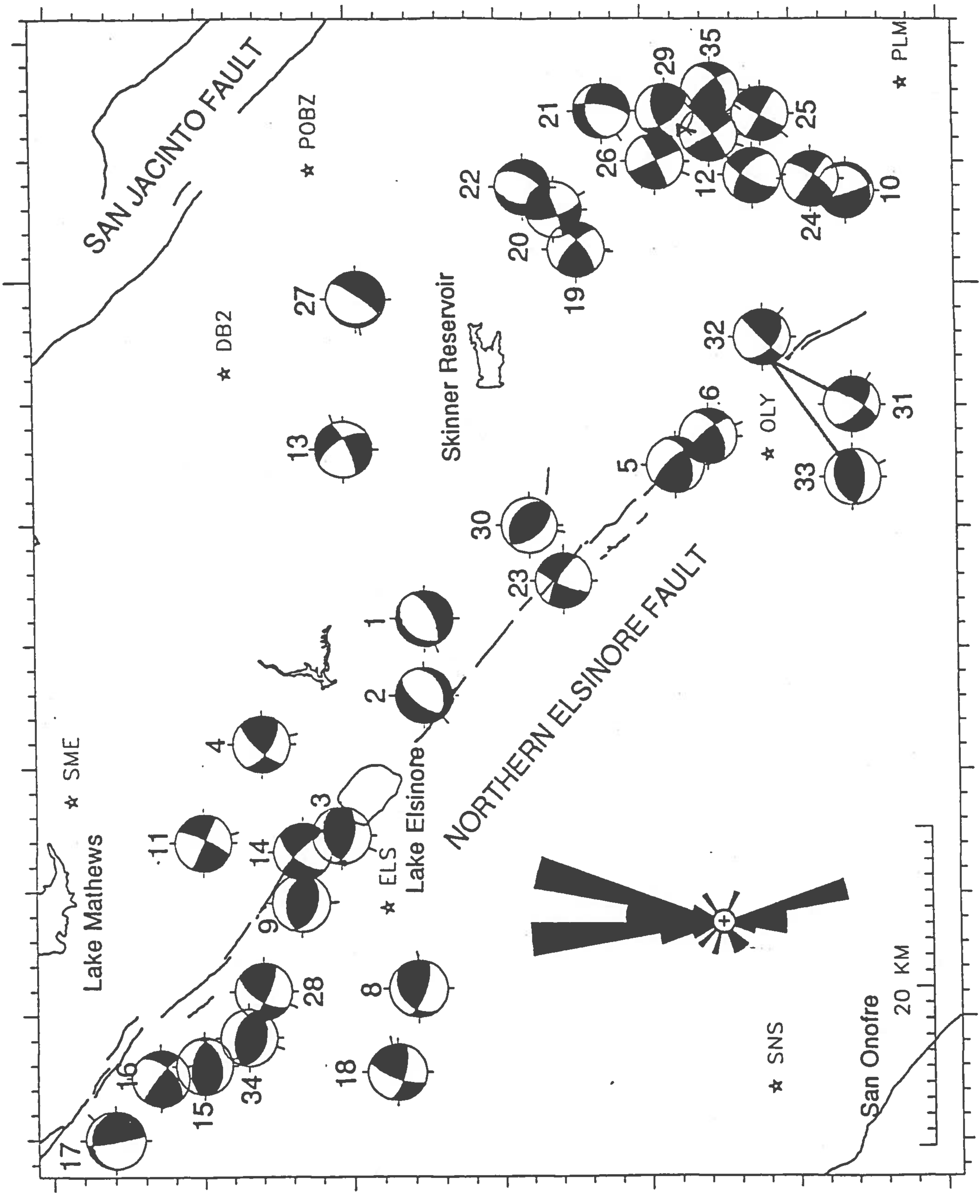

F-7

Figure 1: Lower-hemisphere, equal-area, single-event focal mechanisms for 35 selected earthquakes from the Elsinore-Temecula trough. Compressional quadrants are shaded. Some mechanisms have been moved slightly from their original locations so that focal spheres do not overlap. Inset rose diagram indicates the orientation (10° groupings) of the 35 P-axes; average azimuth is 353°±52°.

F-8

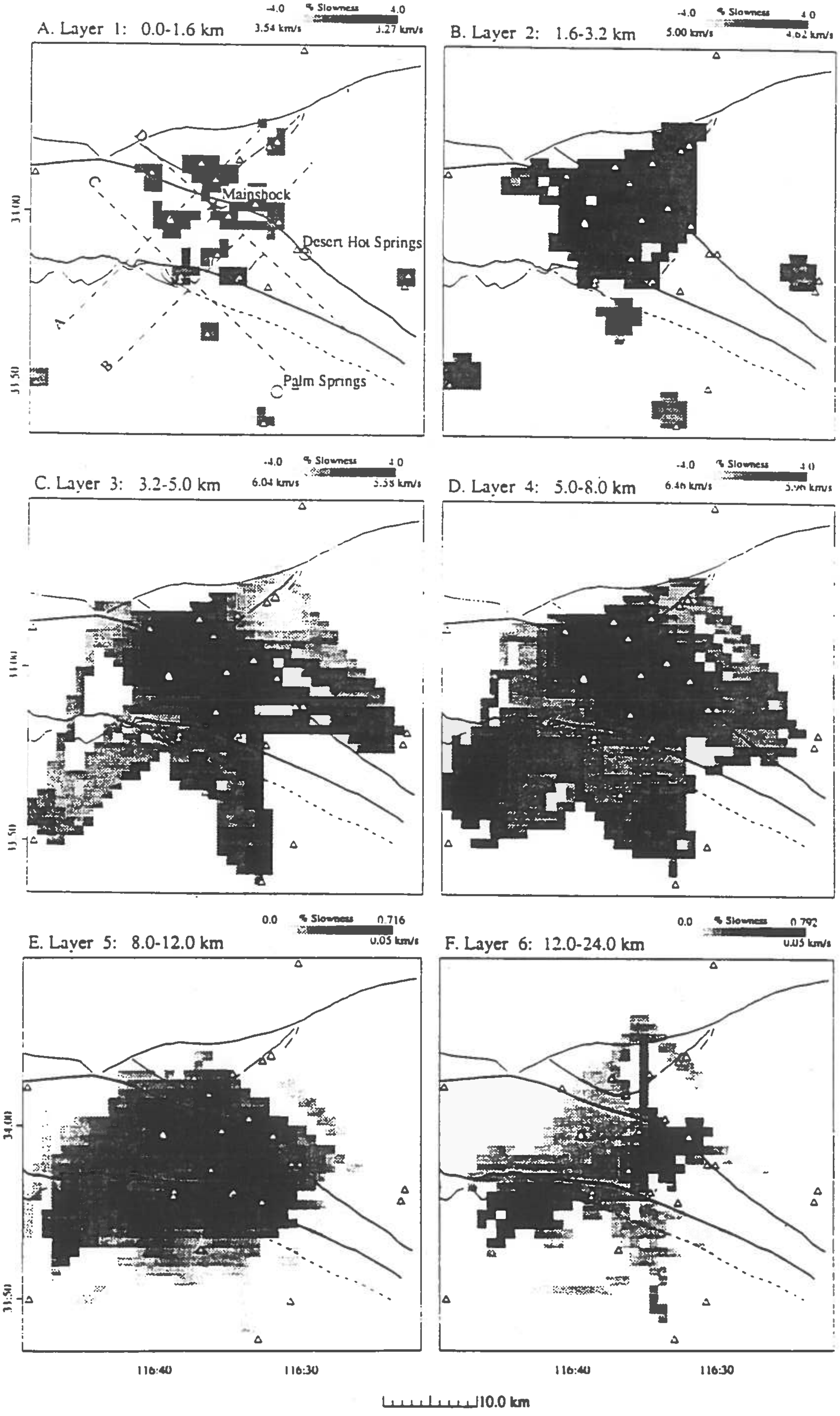

Figure 2. Greyshade plots of P-wave velocity perturbations (in % slowness) relative to a 1-D model for layers 1 through 6, as derived from the 3-D tomographic inversion. Triangles are portable and permanent stations used to monitor the seismicity. (*a*) Line profiles (A – D) reflect cross section orientations shown in figure 4.

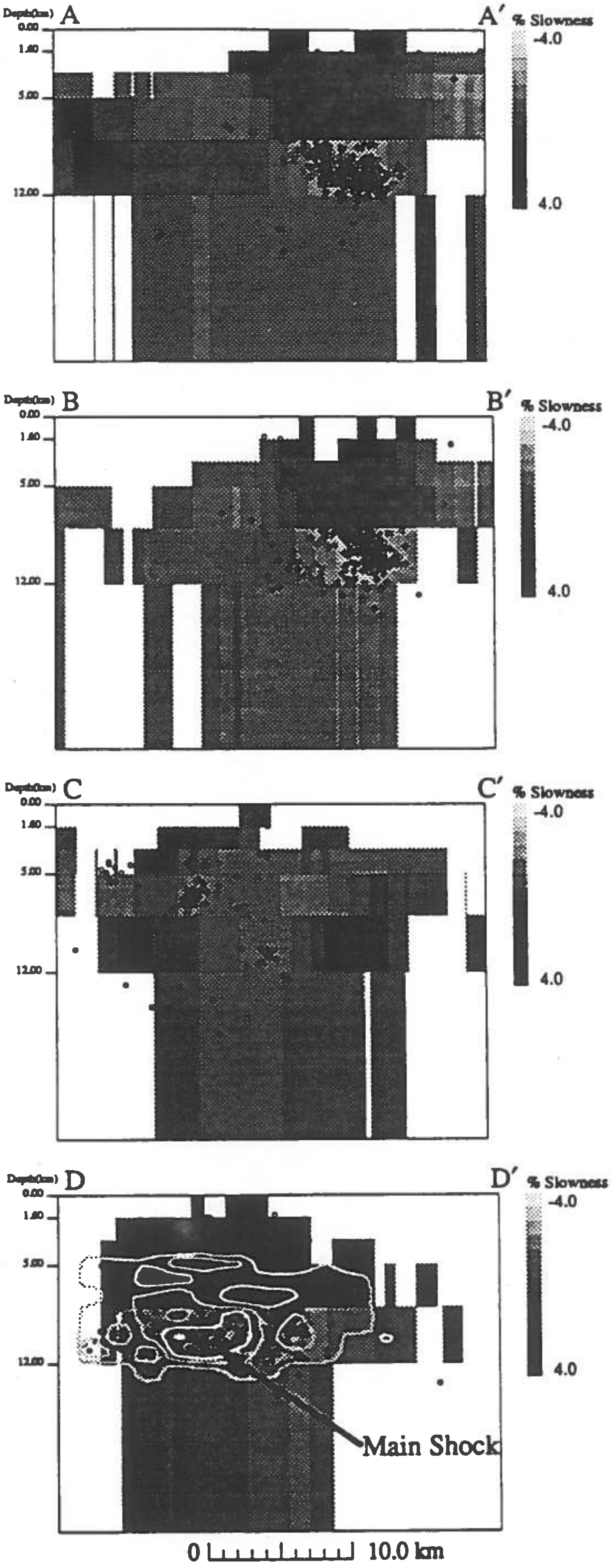

Figure 3. Greyshade vertical cross sections of velocity perturbations (in % slowness) relative to individual layer velocities as specified in the 1-D model. Cross section orientations are shown in Figure 2*a*. Earthquake hypocenters projected from within 5 km to either side are shown as small open circles. In D-D′, superimposed contour lines are the projected dynamic slip distrubution of the NPS mainshock [after *Hartzell*, 1989].

F-10

Fault Kinematics from Earthquakes in Southern California

L. Seeber and John G. Armbruster, Lamont-Doherty Geological Observatory

1. Basic earthquake data. We are generating a file of relocated hypocenters and quality-selected focal mechanisms -- earthquake data ready for structural interpretation -- for the period of good network coverage in southern California (1981-1990). We are accomplishing this task in a single procedure for an area covering most of southern California (32.5N-35.5N; 114.5W-120.0W). We have tried a variety of schemes to obtain accurate locations; as a first iteration, we are satisfied with a joint relocation technique based on location-dependent station-corrections (LDSC). We have divided southern California in 40x55 equal size boxes; corrections were assigned to each box for each of about 175 stations on the basis a subset of the best constrained hypocenters in each box. Other, less frequently used stations were assigned fixed corrections. Hypocenters were obtained by assigning different 1-dimentional velocity structure to each ray path. These path-dependent structures are derived by combining structures obtained from the letterature for ten sub-regions of southern California. Smoothing was applied to the LDSC's according to the density of data. Finally, locations were obtained on the basis of LDSC with smoothing again applied to avoid steps in location bias at the boundaries between boxes. About 20,000 quality-selected hypocenters were obtained. These locations are relatively accurate, but they may have substantial systematic errors. The task in the next stage is to define these errors and to account for them by appropriate modifications of the LDSC's. Results were compared with known locations (e.g., blasts) and with results from other studies involving subsets of the data we are considering. The entire process was repeated with different parameters. Satisfied with the preliminary results, we have proceeded to obtain focal mechanisms by a grid-search scheme we have developed. After quality selection designed to optimize resolution and based on various parameters, we have obtained about 10,000 well-constrained focal mechanisms for southern California. The structural interpretation of the mechanisms and the correlation between seismically defined and mapped faults will provide constraints on systematic location error.

2. A Structural Model of Seismicity. The main contribution of this project will be to provide a set of focal mechanisms for which the nodal plane corresponding to the seismogenic fault has been chosen -- a structural interpretation of the earthquake data. This model, which is now beginning to take shape, includes all mechanisms that can be associated with faults postulated on the basis of the earthquake data. The main criterion for our interpretation will be correlation between focal planes and planes defined by hypocenter distribution. The main test for the model is provided by the correlation with mapped surface faults. We have developed a set of programs for manipulating and visualizing locations and focal mechanisms in 3-D and for assigning fault planes. We intend to expand its capability to include mapped faults and other pertinent data. With these tools, the massive task of interpreting all the available data for California is a realistic one. From our experience in central California, we expect that at least half the focal mechanisms, or about 5,000 events, will be included in our model. We expect our effort to yield a valid and useful interpretation of the data, but certainly not the only possible one. The final product of this effort will include the tools to derive alternative structural models from the mechanisms.

3. Earthquake Prediction. In central California we have used the structural model to monitor changes in stress during 20 years prior to the Loma Prieta earthquake. We found that a sudden change in the pattern of seismicity starting 6 years prior to the main shock could be modeled as a perturbation on the strain build-up caused by hardening of the fault patch about to rupture (Seeber and Armbruster, submitted for publication). A 6 year precursor for a M=7 earthquake is consistent with worldwide data on precursor-time versus magnitude. A structural model of seismicity is a prerequisite for this type of analysis. We intend to search for precursor on past and on future earthquakes in southern California as soon as our first structural model becomes available for this area.

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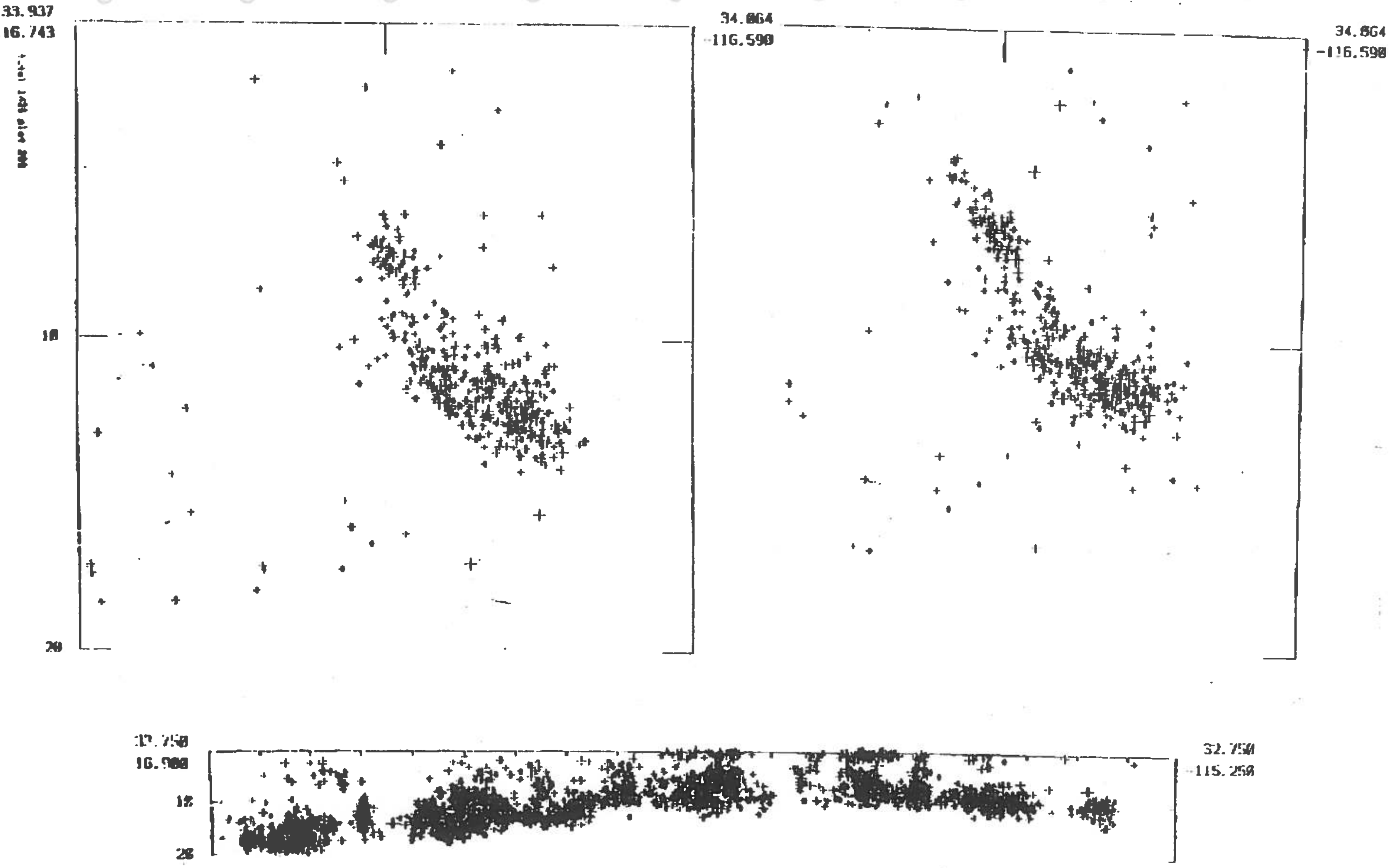

Figure 1. Examples of hypocenters obtained by the location-dependent station correction technique (LDSC). Above: two identical sections across the 1986 North Palm Springs aftershock zone (looking northwest): left by LDSC on data from the fixed network; right by Jones et al., 1988 incorporating data from temporary stations. Compare overall shape of zone; the two sets incorporate different earthquakes. Below: Section along San Jacinto fault (looking northeast). Depth distribution of LDSC hypocenters is similar to depth distribution obtained from detailed studies of data from the Anza Network.

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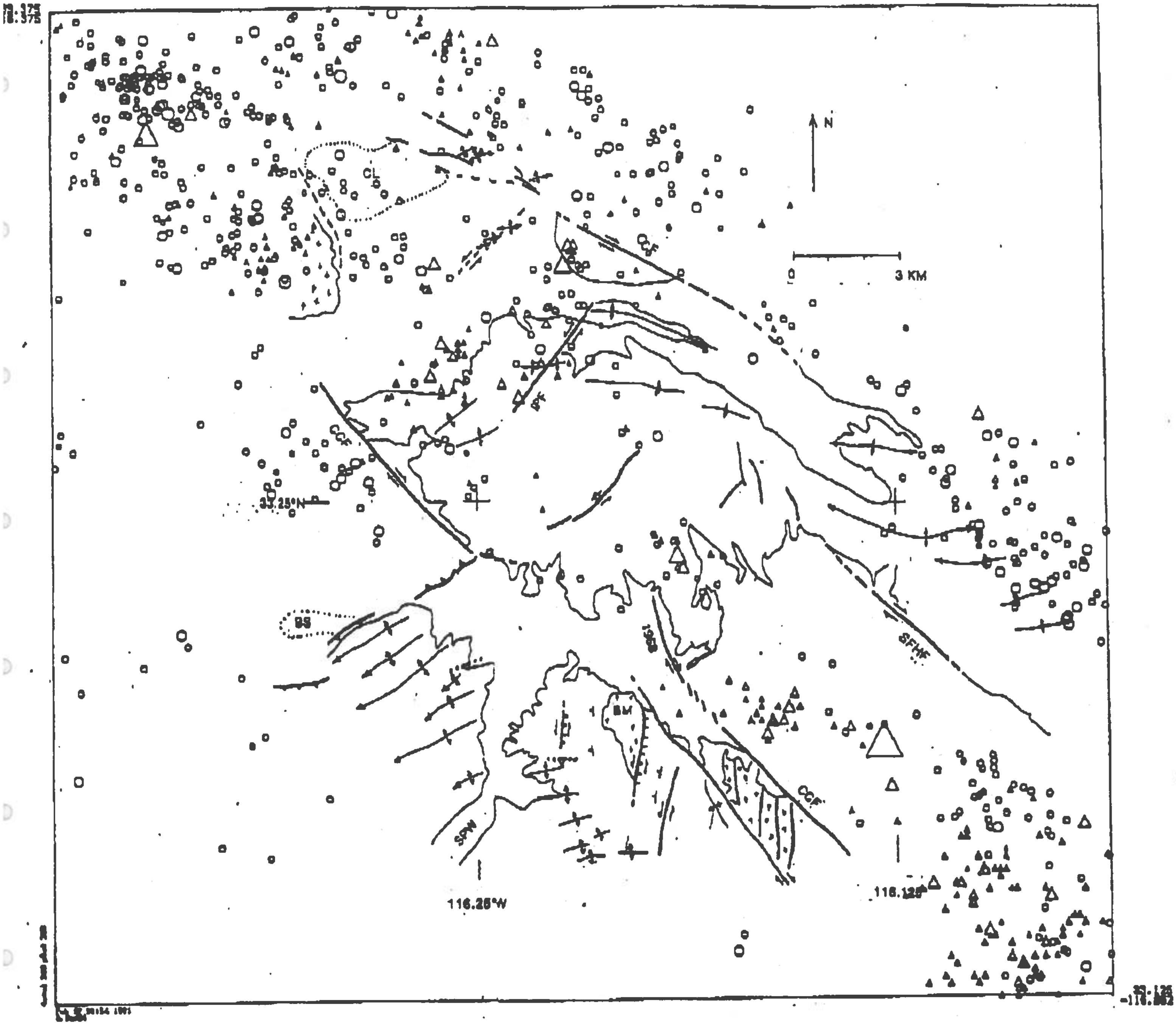

Figure 2. Relocated epicenters and surface structures in the Borrego Badlands area of the San Jacinto fault zone. SFHF=San Felipe Hill fault; CCF= Coyote Creek fault; CF=Clark fault; IPF=Inspiration Point Fault; Cl=Clark Lake ;BS=Borrego Sink; BM=Borrego Mountain. In the structural model of seismicity, many of these earthquake will be represented as a nodal plane with its kinematics. The comparison of this model with the complex pattern of faults and folds will help us to understand the significance of these structures in terms of burried seismogenic faults. A question we wish to address is whether the Borrego Badland tectonic knot along the San Jacinto fault operates only as a barrier, as in the 1968 and 1954 earthquakes, or whether it can also operate as an asperity and be included in a very large rupture.

Project 5

Research on Regional Earthquake Source Imaging and Regional Propagation

Thorne Lay, UCSC

Investigations

Developing regionalized models for short period Rayleigh wave propagation the western U.S. Conducting synthetic simulations with the CMT inversion code of H. Kawakatsu to assess the applicability to near-real time inversion of the long period waves recorded for regional California earthquakes.

Results

We have implemented a new generalized inverse theory approach to tomography. In collaboration with Howard Patton, this method is being applied to regionalized inversion for many surface wave paths in the western U.S. and California, to develop dispersion models that can be used for stable inversion of regional surface waves from southern California events. Dr. Zhang, Dr. S. Schwartz and myself are completing a study of surface wave dispersion between PAS and SCZ broadband stations.

We are testing the sensitivity of the CMT inversion method to source mislocation, inaccurate Green's function and spatial distribution of the broadband array. Dr. Keiko Kuge installed the CMT code here at UCSC. Our first data application will involve the 1991 Sierra Madre earthquake.

The projects that we have undertaken involve long-term development of rapid regional wave inversion methods, and extensive testing of the sensitivity and robustness of the inversions is required.

Publications

Ammon, C. and J. Vidale, Tomography without rays, B.S.S.A., submitted June 1991

F-14

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September 5, 1991

Dr. Egill Hauksson
Chairman: Group F Working Group
Southern California Earthquake Center

Re: Research progress report for U.C.S.C. project: "Research on Regional Earthquake Source Imaging and Regional Propagation", P.I. Thorne Lay ($30,000, April 1, 1991-January 31, 1992).

Dear Egill:

My group's progress on this project is summarized below. The personnel involved are myself, postdoctoral researchers Dr. Charles Ammon, Dr. Keiko Kuge, and Dr. Jiajun Zhang, and graduate student Jeroen Ritsema. Dr. Ammon is concentrating on developing regionalized models for short period Rayleigh wave propagation in the western U.S.. He has implimented a new generalized inverse theory approach to tomography, described in the preprint "Tomography without rays" by C. Ammon and J. Vidale (B.S.S.A. submitted June 1991). In collaboration with Howard Patton, this method is being applied to regionalized inversion for many surface wave paths in the western U.S. and California, to develop dispersion models that can be used for stable inversion of regional surface waves from southern California events. Dr. Zhang, Dr. S. Schwartz and myself are completing a study of surface wave dispersion between PAS and SCZ broadband stations, which will augment the data set used by Ammon and Patton.

Graduate student Jeroen Ritsema is conducting synthetic simulations with the CMT inversion code of H. Kawakatsu to assess the applicability to near-real time inversion of the long period waves recorded for regional California earthquakes. We are testing the sensitiviyt of the method to source mislocation, inaccurate Green's function and spatial distribution of the broadband array. An AGU abstract is being written this week for presentation at the Fall meeting. Jeroen is an excellent Ph.D. student who came here from Utrecht, and he has good theoretical preparation for this project. Dr. Keiko Kuge installed the CMT code here at UCSC, and has been a major source of knowledge about the program. Our first data application will involve the 1991 Pasadena earthquake, for which we have collected the Terrascope and UCB data, and a request is in for LLNL and Nevada recordings.

The projects that we have undertaken involve long-term development of rapid regional wave inversion methods, and extensive testing of the sensitivity and robustness of the inversions is required. We are about on schedule relative to our expected rate of progress on these efforts. We have also closely coordinated with Caltech in the choice of instrument sensors and recording equipment for the two new UCSC VBB stations which will be deployed, to abet instrument and data standardization.

Sincerely,

Thorne

Thorne Lay
Director, Institute of Tectonics
Earth Science Dept.
UCSC

Group G: Physics of Earthquake Sources

Group Leader: Leon Knopoff

Laboratory Studies of the Effects of Liquid Invasion on Frequency Dependence of Intrinsic Q and Scattering Q	Gao and Aki (USC)	G-1
Dynamics of Fault Interactions	Davis (UCLA)	G-3
Spontaneous Rupture Propagation across Fault Steps	Harris (UC-Santa Barbara)	G-6
Simulation: Random Stress and Earthquakes	Kagan (UCLA)	G-7
Pattern Recognition Methods for Estimation of Earthquake Probabilities	Katz and Aki (USC)	G-8
Barrier Model of Seismicity with Geometrical Inhomogeneity and Creep Rheology and Simulated seismicity on a Hybrid Barrier/Asperity Model	Knopoff (UCLA)	G-13
Evaluation of the Characteristic Earthquake Concept in Southern California	Rice (Harvard)	G-15
The Earthquake Cycle in a Simple Model: Comparing the Behavior of the Model with Seismological Observations	Shaw (UC-Santa Barbara)	G-17
Application of Models of dynamical Systems to Seismicity, Earthquake Patterns, and Predictions	Scholz (Columbia)	G-18
Precursor Phenomenlogy and Modeling	Levshina (UCLA)	G-21

G-1

Frequency dependency of intrinsic Q and scattering Q, how it is effected by liquid invasion. (Progress Report)

Gao ,L.S. and K.Aki, USC

1, To estimate the observable Q-factor change related to liquid invasion and partial melting in the earth, we've implemented the data analyses on digitized records from experiments on attenuation. The analyses emphasize on frequency dependence and liquid effect of Q-factor;

2, We find that liquid contents raise the attenuation of waves in the whole range of frequency under research (0.2MHz-7.5MHz). If we recognize that there are several different mechanisms for attenuation, we should suggest that the liquid may affect all mechanisms which function in the sample of Al-Ga in the researched frequency range;(Fig.1)

3, We notice that one of the peaks of attenuations observed have a strong correlation with the source spectrum. We may suggest that this is caused by the fact that one of the attenuation mechanisms among our observed attenuation is amplitude dependent;(Fig.1)

4, We suggest that the whole measured attenuation consists of at least two parts

$$Q^{-1} = Q_n^{-1} + Q_l^{-1}$$

where Q_n^{-1} is the nonlinear attenuation due to process such as Coulomb friction, which is expressed as

$$Q_n^{-1} = \alpha \cdot \varepsilon$$

where α is a constant of material, ε is the strain amplitude.

Thus we can use the first peak(amplitude dependent part) which is higher than linear attenuation to calibrate the nonlinear attenuation coefficient,α, and then use the coefficient to deduct the nonlinear part from the whole measurement, if we recognize that the attenuation of Coulomb friction is frequency independent.

Q_l^{-1} is the remaining linear part. We then obtain a linear attenuation as function of frequency, which leads to a constant Q_l^{-1} in the range of 2-6 MHz. Also we may find that when frequency is higher than 6MHz there is another high attenuation tendency. The related mechanism is likely due to the internal friction at the grain boundary or molecular levels. This internal friction is different from Coulomb friction.(Fig.2)

5, The preliminary result reminds us that the nonlinear attenuation may exist in all records but is often masked by some other predominant mechanisms depending on the circumstance.

G-2

Fig 1: Correlation between source and attn

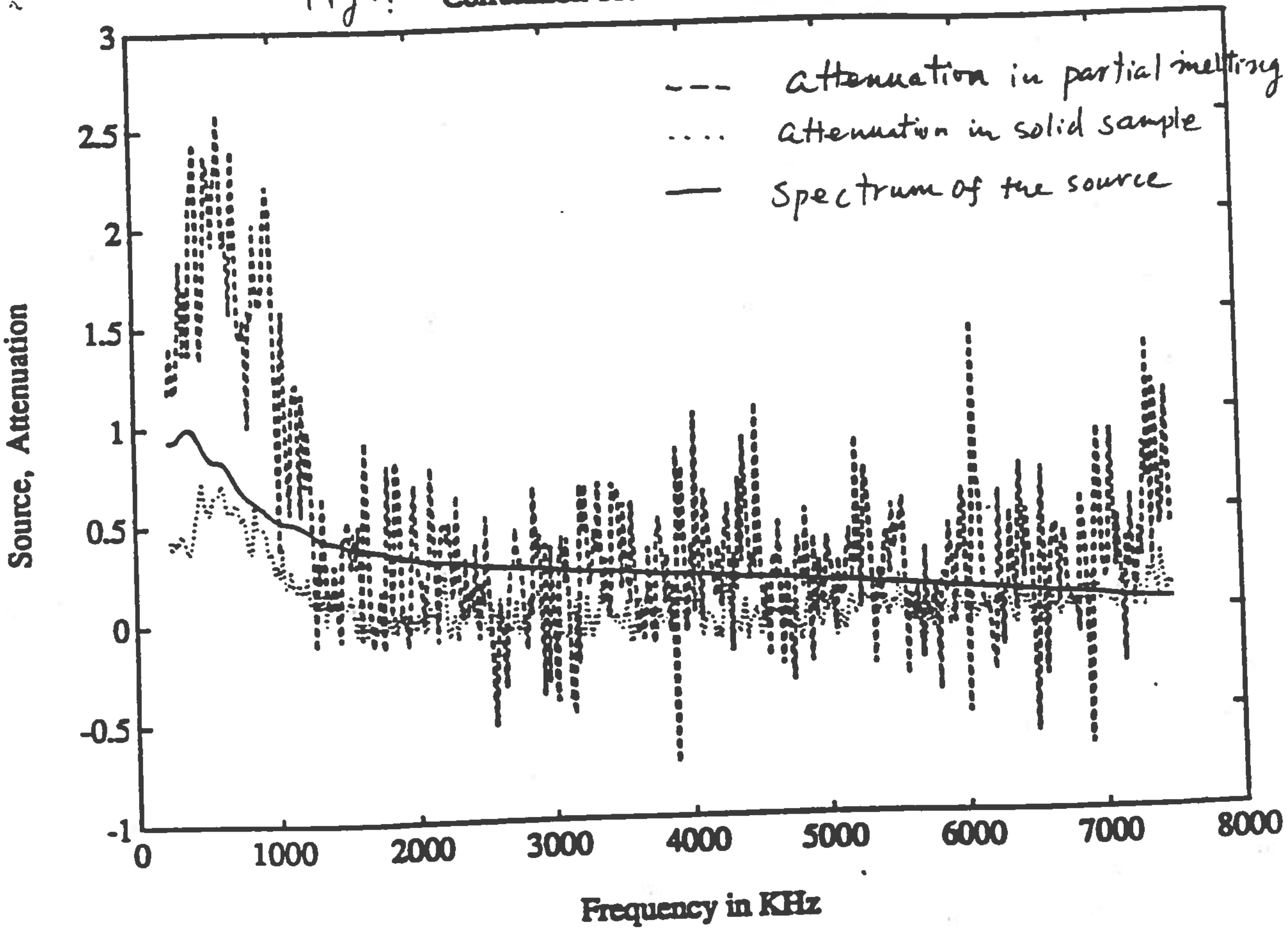
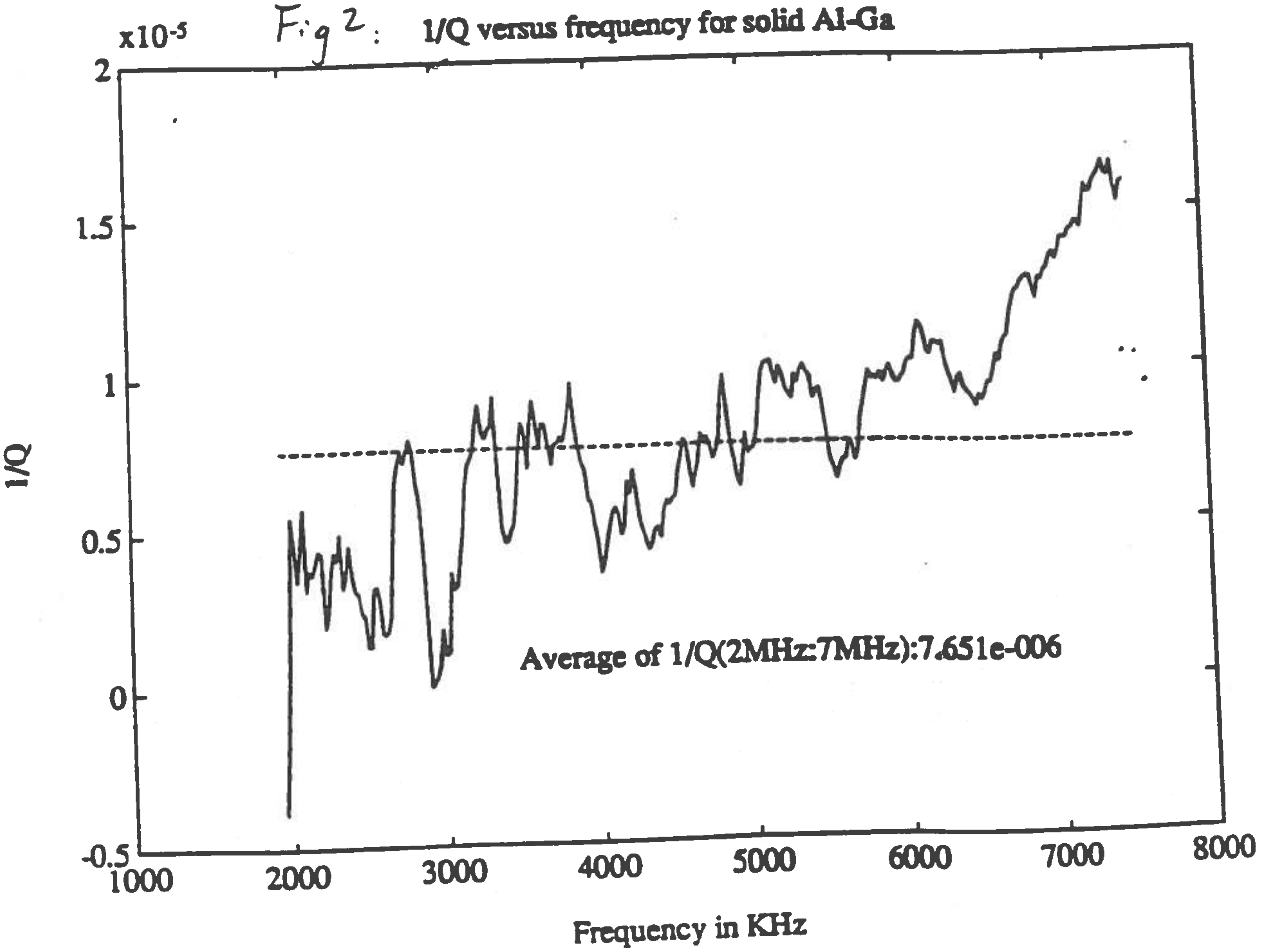


Fig 2: 1/Q versus frequency for solid Al-Ga



G-3

Dynamics of Fault Interactions

Paul M. Davis, UCLA

We have used a connection machine to model 1000 interacting antiplane cracks subjected to a shear field. By taking advantage of the massively parallel processing (8192 processors) of the connection machine we are able to solve the interaction boundary integral equation faster (factor of more than 50) than on the IBM 3090. A micro-processor is assigned to each node. A program was written to generate the co-ordinates of 1000 random, non-intersecting, strongly interacting cracks (figure 1). Crack sizes were chosen from a power law distribution. Approximately 9 nodes per crack yielded a 8,800x8,800 interaction matrix to be inverted to find nodal displacements which give a constant stress condition on the crack surfaces .

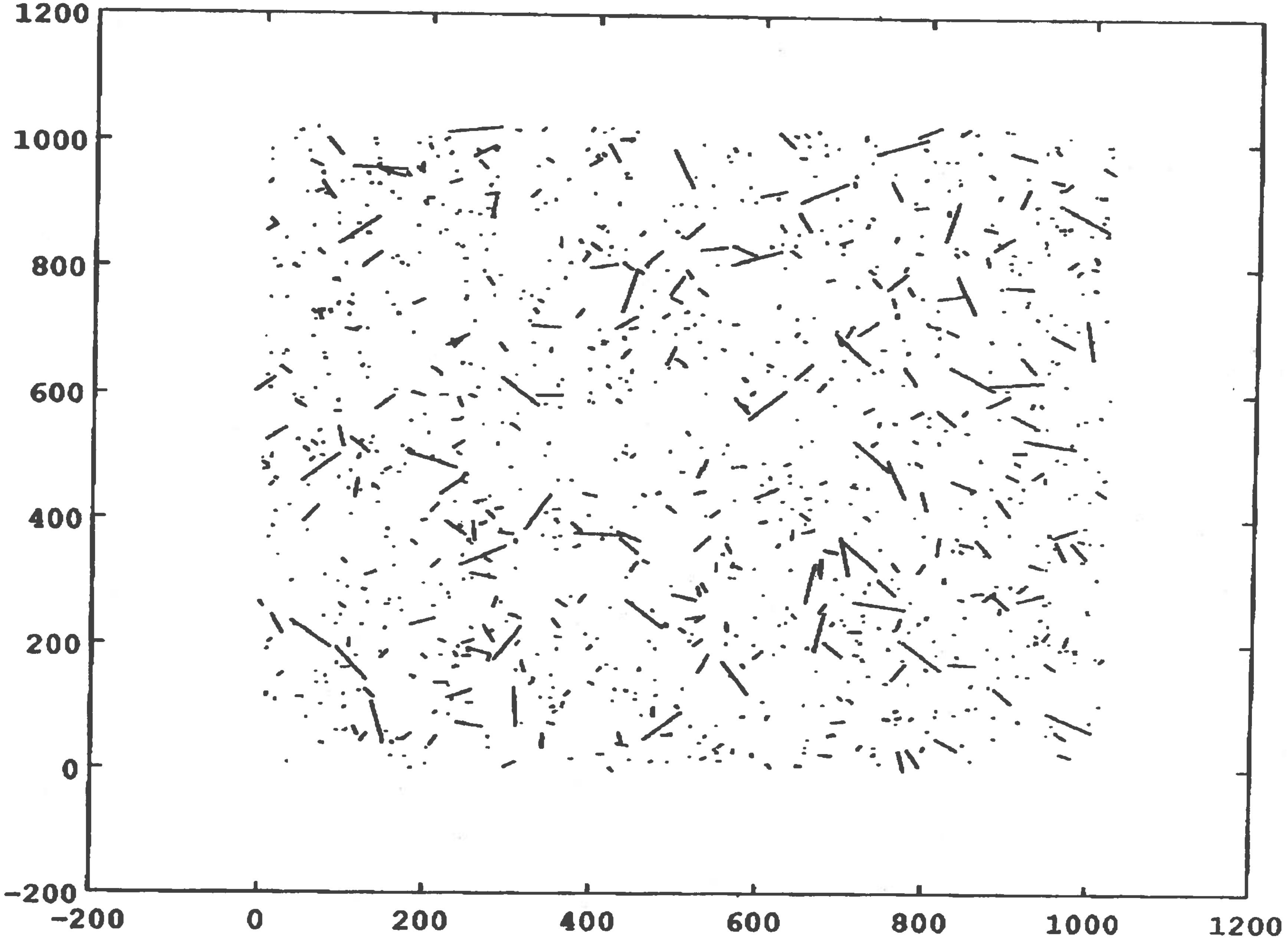
The antiplane boundary integral method has been tested against a number of canonical, analytic solutions 1) the isolated antiplane crack (Knopoff, 1958), 2) the bent antiplane crack (Davis and Knopoff, 1991), 3) the infinite periodic array of colinear cracks (Koiter, 1959) and 4) a crack with a slip-weakening displacement function. In all cases, increasing the number of nodes brings the numerical and analytical solutions into agreement. New problems that have been investigated include 1) overlapping cracks 2) the energetics of crack propagation out of plane and 3) multiple interactions.

For the 1000 crack problem the energy of the interacting crack ensemble is only 6% greater than for the non-interacting case. However some cracks have displacements that are orders of magnitude different from values if they were non-interacting. Enhancement and reduction of the non-interaction displacement fields caused by interactions (histogram figure 2), to a large extent cancel out.

This work sets up the framework to handle the problems originally proposed., i.e., to examine model seismicity by iterating the model in time with crack slip determined by a stress corrosion power law or, in extreme cases, a stress intensity failure criterion; namely to examine conditions for foreshocks. Future steps involve: comparison of bulk properties with values calculated from pairwise multiple scattering processes (Chatterjee et al., 1978); modelling crack propagation through a heterogeneous stress field arising from pre-existing defects and determination of fracture roughness; extension to 2D inplane Green's functions rather than antiplane functions. The objective is to use this type of modelling as a test bed for examining simple physics models of the effects of fault interactions.

G-4

1000 Interacting Cracks



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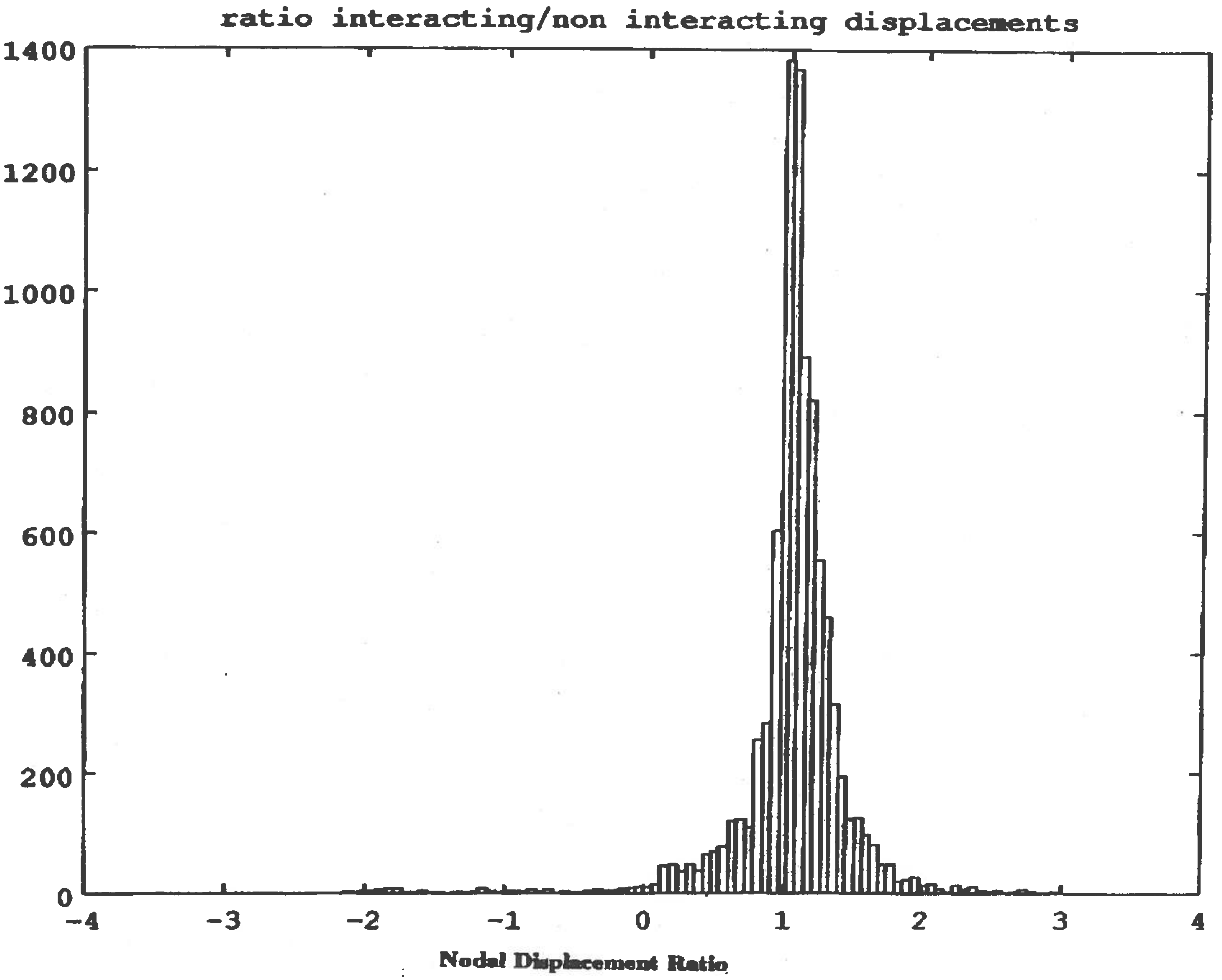
2.


ratio interacting/non interacting displacements
1400
1200
1000
800
600
400
200
0
-4
-3
-2
-1
0
1
2
3
4
Nodal Displacement Ratio

G-6

SCEC RESEARCH PROGRESS REPORT FOR YEAR 1

RUTH A. HARRIS
(formerly at UCSB, now at USGS, Menlo Park)

Proposal Title: Spontaneous Rupture Propagation across Fault Steps
Working Group: Physics of Earthquake Sources (Working Group G)

Summary:

My research involved using a finite-difference computer program to numerically simulate spontaneous rupture propagations across fault steps. The simulations were two-dimensional calculations, implying plane strain. The object of this study was to determine how parallel (non-collinear) vertical strike-slip faults interact and thereby affect the dynamic earthquake rupture process. Primarily, the intention of this 2-d study was to determine the maximum distance which an earthquake rupture could jump to a parallel fault segment, and if it would continue to propagate on the second fault segment. The results of this two-dimensional study are that 5-km appears to be the maximum 'jumpable' distance for an earthquake rupture, assuming parallel vertical strike-slip faults set in linearly elastic material. This result is also supported by field observations which show 4-5 km to be the upper limit, as evidenced by the great M8 Erzincan earthquake which ruptured through fault steps in the Northern Anatolian fault in 1939. The implication of this result for the San Jacinto fault is that it would be hard to predict if an earthquake could jump a step in the San Jacinto fault since most of the segments are separated by less than 4 km.

Two additional results of this study are that 1) the rupture velocity is very significant in determining the maximum 'jumpable' distance, and that 2) dilational steps appear to slow the rupture more than compressional steps do, leading to a lower apparent rupture velocity.

For Year 1 of the SCEC I have also started to look at the case of earthquakes which re-rupture the first fault segment. This was done by using the static stress field, which remains after a rupture has propagated down the first fault segment, as the initial conditions for a second rupture. The dynamic rupture on the first fault segment changes the shear stress field on the first fault segment, and it also changes both the shear stress and normal stress fields on the second, non-collinear fault segment. The results for the case of a 30 bar stress drop, supershear rupture velocity, and a 4.5 km stepover width show that the step could not be jumped the first time the first fault segment ruptured. I then used the residual stress field as the starting conditions for a second earthquake on the first fault segment. The rupture propagated down the first fault segment, as before, but then unlike the first case, the rupture was able to jump to the second fault segment. Another simulation, where a third earthquake ruptures the faults will be done in the near future.

A separate study which I have just started will include 3-d finite-difference numerical modelling of the dynamic interaction of parallel strike-slip faults. With this study I will be able to determine which waves contribute to the rupture jumping across the steps, and I should also be able to determine the vertical components of displacement. I hope to continue discussion with SCEC scientists about this fault interaction modelling at future SCEC meetings, although I will be ineligible for NSF-based SCEC salary support for the year 10/91 - 10/92 since I am at present a National Research Council/USGS postdoc.

G-7

Kagan, Y. Y., (UCLA): SCEC 1991 annual summary report.

During the period from April 1, 1991, to October 21, 1991 I have made the following work in two fields: (a) Master model, and (b) Physics of earthquake source.

(a) Papers [5], [7], and [10] (see below) are dedicated to certain aspects of the evaluation of the seismic risk. In [5] we test the validity of the seismic gap model. We find that the hypothesis of increased earthquake potential after a long quiet period can be rejected with a large degree of confidence. The data suggest that places of recent earthquake activity have larger than usual seismic hazard, whereas the segments of the circum-Pacific belt with no large earthquakes in recent decades have remained relatively quiet. Paper [7] proposes quantitative criteria for the optimization of earthquake prediction methods, and for the appropriate choice of earthquake mitigation measures. Manuscript [10] evaluates the 'characteristic' earthquake hypothesis. Based on the results of other researchers and our own tests, we show that the proofs of the 'characteristic' earthquake hypothesis can be explained either by various statistical biases, or by statistical artifacts.

(b) Papers [4], [8], and [9] determine quantitatively the 3-D stochastic geometry of earthquake faulting as it is revealed in concentrations of hypocenters and in orientations of focal mechanisms of earthquakes. We show that the rotation of earthquake focal mechanisms is controlled by the Cauchy distribution, this distribution being predicted by both theoretical arguments and by computer simulation of rupture initiation. The above papers and our earlier work finally demonstrate that earthquakes are influenced by a 3-D random stress which is due to defects (earthquake faults), both known and unknown. Therefore, these results give us a confidence that general ideas of simulations of earthquake rupture propagation through elastic medium with defects are correct, and we will use the Cauchy distribution to model non-planarity of rupture propagation. We have also determined parameter values of the Cauchy distribution, thus we are able to simulate the initial geometry of defects which should correspond to the pattern of real earthquake faults.

Papers [1], [2], and [3] describe scale-invariant properties of earthquakes: the spatial self-similarity of hypocenter distribution, the power-law distribution of earthquake size, and fractal temporal features of earthquake occurrence. Although these papers are not connected directly with the SCEC immediate goals, I believe that the results of the papers contribute to our understanding of the earthquake physics, and allow us to define a proper class of models for earthquake focal process. Manuscript [9] reviews in a more popular form the scale-invariant properties of seismicity, trying at the same time to argue that there is great similarity between two modes of condensed matter deformation: fluid turbulence and the brittle fracture of rock material which results in earthquakes. This similarity might be used to gain a better insight into both of these phenomena.

Published or prepared papers:

1. Kagan, Y. Y., 1991. Fractal dimension of brittle fracture, *J. Nonlinear Sci.*, 1, 1-16.
2. Kagan, Y. Y., 1991. Seismic moment distribution, *Geophys. J. Int.*, 106, 123-134.
3. Kagan, Y. Y., 1991. Likelihood analysis of earthquake catalogs, *Geophys. J. Int.*, 106, 135-148.
4. Kagan, Y. Y., 1991. 3-D rotation of double-couple earthquake sources, *Geophys. J. Int.*, 106, 709-716.
5. Kagan, Y. Y., and D. D. Jackson, 1991. Seismic gap hypothesis: ten years after, *J. Geophys. Res.*, in press.
6. Kagan, Y. Y., 1991. Seismicity: 'Turbulence' of solids, *Nonlinear Sci. Today*, accepted.
7. Molchan, G. M., and Y. Y. Kagan, 1991. Earthquake prediction and its optimization, *J. Geophys. Res.*, submitted.
8. Kagan, Y. Y., 1991. On geometry of earthquake fault system, *PEPI*, submitted.
9. Kagan, Y. Y., 1991. Correlations of earthquake focal mechanisms, *Geophys. J. Int.*, submitted.
10. Kagan, Y. Y., 1991. Statistics of 'characteristic' earthquakes (manuscript, in preparation).

Invited talk during this period: American Geophysical Union (AGU) Spring Meeting at Baltimore, May 29, 1991, (Union meeting). Talk title: *Geometry of Earthquake Faulting*.

G-8

Danger function and Adaptive Pattern Recognition in Earthquake Analysis.

S.Katz, K.Aki
University of Southern California

A Danger Function and sets of basis and complex time-dependent attributes were introduced and calculated for the region of Southern California. In this work t he Danger function was defined for each month as the maximum magnitude of the earthquakes during respective one month time-window. It shows the sequence of large earthquakes and prediction of its values is equivalent to prediction of time and magnitude of the large earthquakes. Among the basis attributes we studied were the following ones: a) the stability of the spatial earthquake distribution calculated in a moving time window, b) the number of earthquakes with a magnitude larger then a given threshold, c) the average and maximal magnitude of earthquakes in a moving time window, d) the differences in percentage of earthquakes or in the number of earthquakes for several magnitude ranges calculated in a moving time window , e) the parametric representation of the depth distribution of the earthquakes in a moving time window, f) fractal parameters relating to the time-space distribution of earthquakes g) clustering parameters of spatial distribution of the earthquakes defined as time functions. Complex attributes are defined as linear and quadratic combinations of basis attributes. The maximal number of mutually uncorrelated complex attributes constructed as linear combinations of basic attributes is defined by the results of time - eigenvalue analysis. It is based on calculation of the set of eigenvalues of a matrix of crosscorrelation functions of basis attributes. The maximal number of linearly independent complex attributes is equal to the number of nonzero eigenvalues. The results of time-eigenvalue analysis show that in the case of 16 basis attributes, there is 7 to 9 nonzero eigenvalues (depending from the width of the time-window used to calculate the matrix of crosscorrelation functions).

The two methods were used to process the set of seismic attributes and to predict values of the Danger Function: a) Linear multi-parameter regression and b) Adaptive Neural Networks (ANN) modified in such a way that it is capable to work efficiently with small training data sets.. Linear method failed.(figure 3.). Results of the use of ANN look promising. The two layer adaptive neural network (ANN) was specifically designed and trained to generate a positive signal several months before large earthquakes. In experiments with this neural network the training data set was formed with the use of basis and complex attributes calculated in a time window with the width 15 to 80 month. The results of the use of ANN for two regions of Southern California are shown in figures 1 and 2. (Figure 1: 119^0 > longitude > 115^0; 36^0 >latitude > 33^0; Figure 2 : range of latitudes is the same as in figure 1, shown in figures 1 and 2.34^0 >latitude > 32^0 In these figures the dashed line shows the danger function and continues line - the output of the Neural Net trained to generate a positive signal two months prior large earthquakes. Training was performed continuously in the moving time-window with the width 15 months. Respective maxima of the danger functions and of the output of the Neural Network are marked by the same indexes. In both cases the two layers ANN with three nods in the hidden layer was used. One can see that before large earthquake the amplitude of the ANN signal is large while in the absence of large earthquakes the output signal as a rule is small or zero. This means that ANN may be used to generate artificial earthquake precursors. Figure 3 shows the results of the earthquake prediction for the second region based on the use of maltivariate regression. One can see that results of prediction are much poorer than those shown in the figure 2. The following conclusions follow from results of our experiments with ANN and linear methods of prediction of danger function:

a) The fact that linear prediction scheme failed and ANN was successful means that there is nonlinear interdependence between the set of seismic attributes and the Danger function. Therefore crosscorrelation,showing measure of linear interdependence between individual attributes and the sequence of large earthquakes, cannot serve as indicator of a value of attribute in earthquake prediction methodology.

b) Individual attributes taken separately are unreliable predictors.

c) The probability of occurrence of a large earthquake is defined by seismic conditions in an area much larger then the rapture zone. This means that faults' interactions may play important role in earthquakes' occurrence

d) The most effective training of the ANN was performed in a narrow time-window:15 to 20 months.

e) The signal at the output of the neural network that uses as its input a set of large number of seismic attributes may serve as an artificial earthquake precursor.

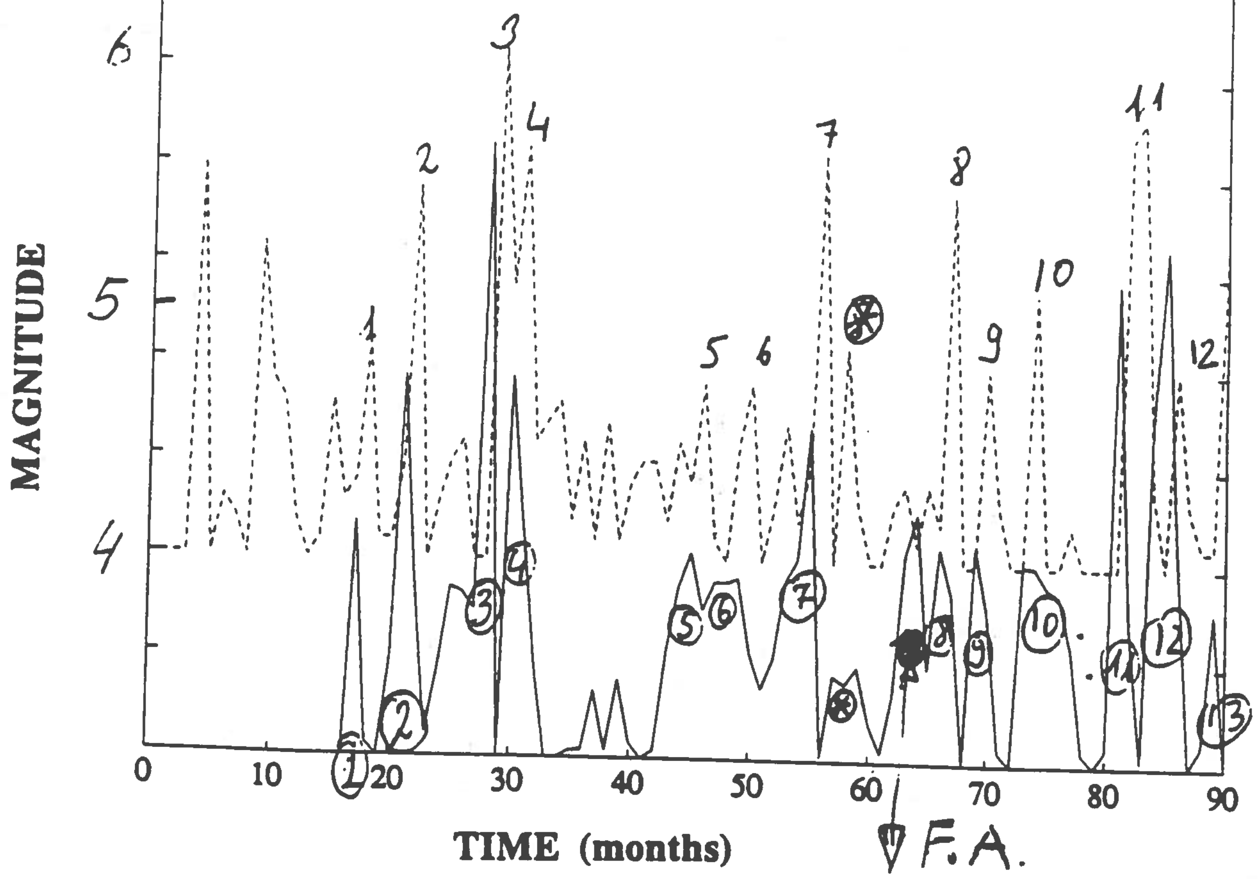


Figure 1 Danger Function (dashed line) and the output of ANN (continuous curve) for the the part of South California region with the range of latitudes: 36^0 >latitude > 33^0 . Respective maxima on both curves are marked by the same indexes.

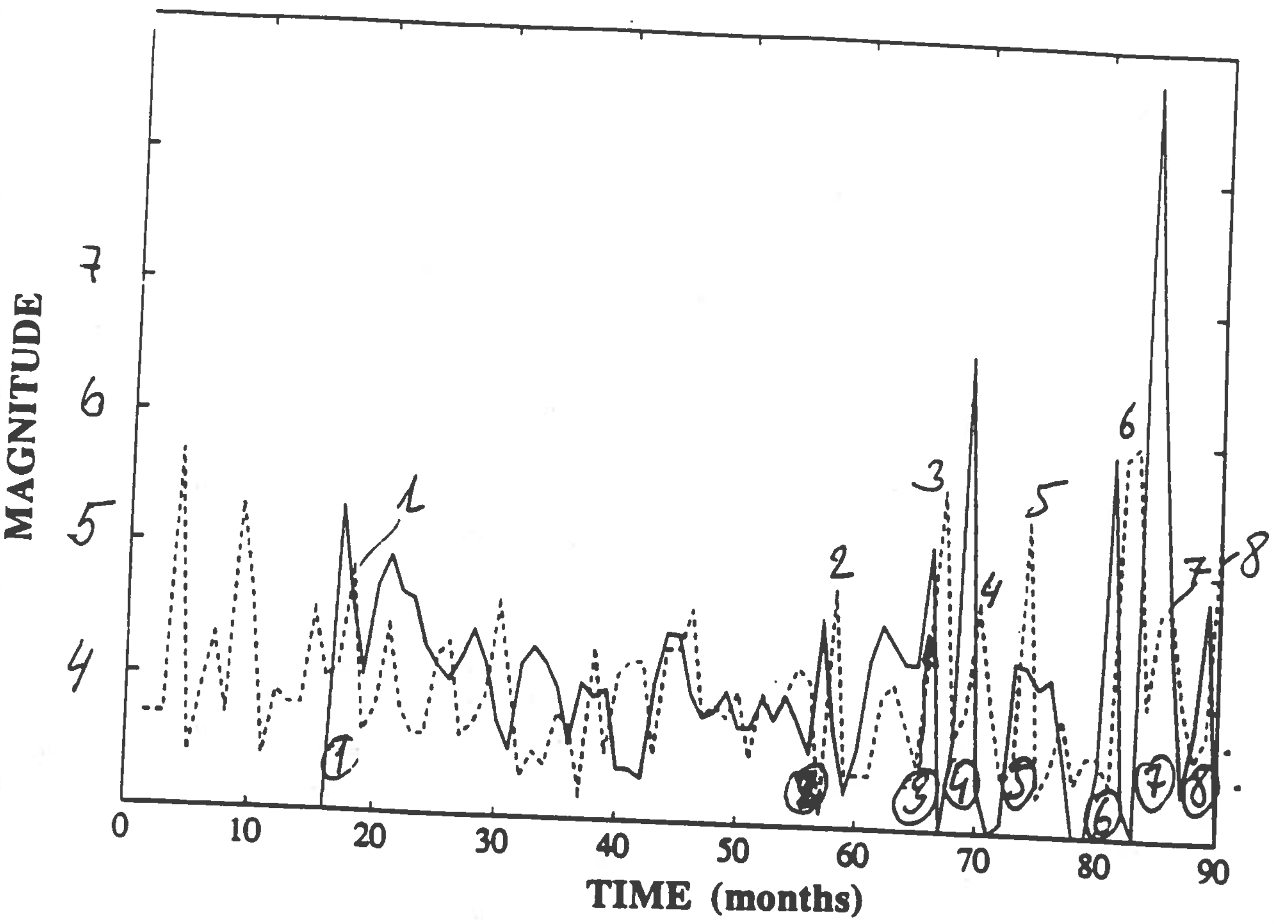


Figure 2 Danger Function (dashed line) and the output of ANN (continuous curve) for the the part of South California region with the range of latitudes: 34^0 >latitude > 32^0 . Respective maxima on both curves are marked by the same indexes.

G-12

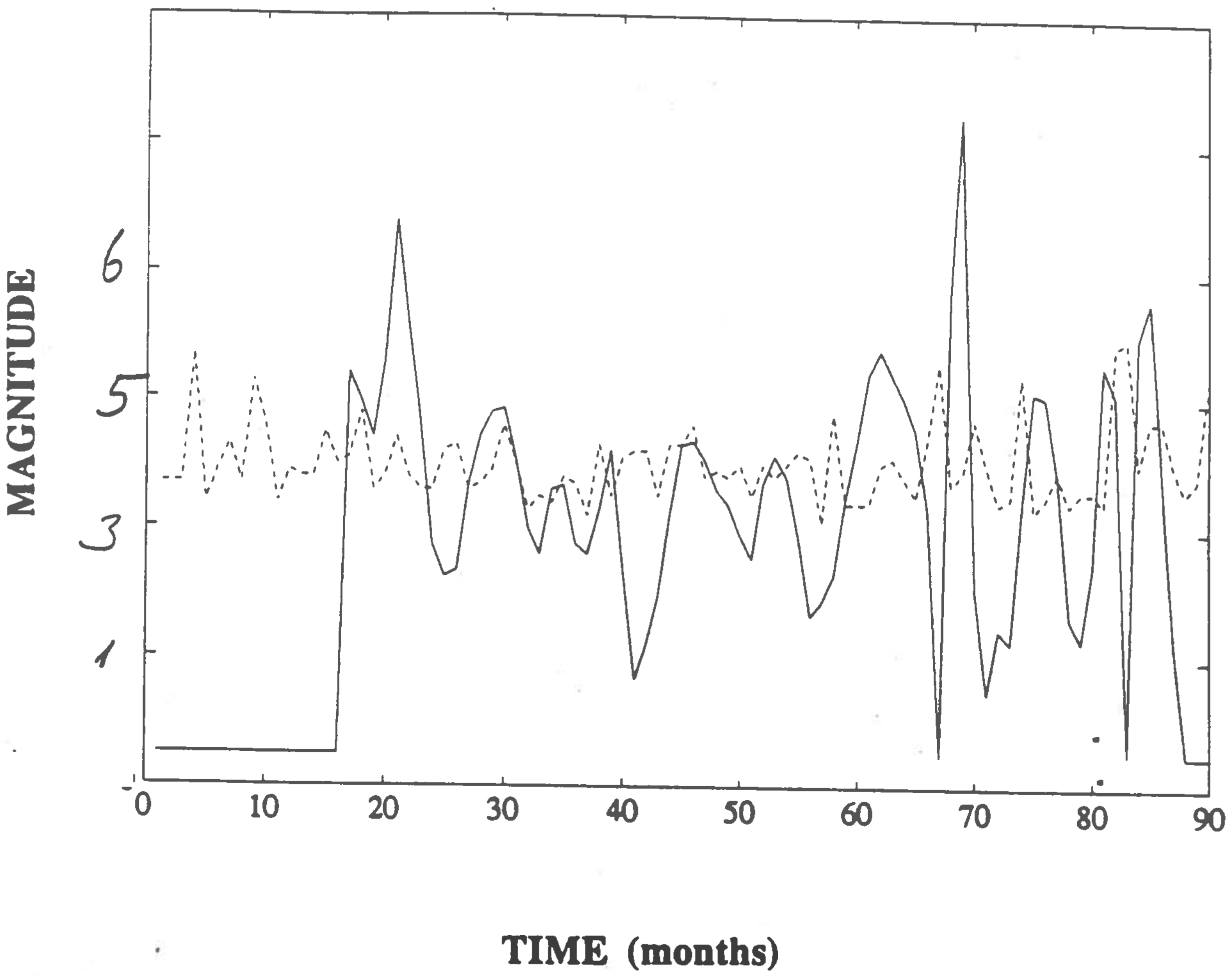


Figure 3 Danger Function (dashed line) and the result of earthquake prediction based on the multivariate regression (continuous curve) for the the part of South California region with the range of latitudes: 34^0 >latitude > 32^0 .

G-13

PROGRESS REPORT OF LEON KNOPOFF FOR WORK PERFORMED UNDER SCEC AUSPICES

Contemporary studies of variants of the Burridge-Knopoff model, including the quasistatic version of Bak, et al., and the dynamics version of Carlson and Langer, make use of stress-free boundary conditions at the edges of the lattice. Under this end condition, the largest events do not have zero motion at the edges of fractures. Work performed prior to the beginning of this project showed that if we used realistic end conditions on a B-K model of seismicity, we had to introduce inhomogeneities somewhere into the model in order that all cracks be "confined", i.e. that there be no events for which the largest motions are at the edges. We have introduced fluctuations in frictional breaking strength at lattice sites and have retained the properties of homogeneity in all the other parameters. We have assumed that, because the fault geometries are shown to be fractals, the breaking strengths of the frictional contacts will be fractally distributed. We have also assumed that the friction drops to its dynamic value instantly upon breaking of a frictional contact, and that radiation damping is the principal dynamical mechanism of energy loss.

Earlier as well as recent results have shown

a) that seismicity is largely governed by the distribution of barriers, i.e. loci of high breaking strength

b) that small scale-seismicity occurs in both one-and two-dimensional models at those places where strengths are low and large events occur when the strengths are great. We believe the mutual exclusivity of these regions can be made consistent with seismicity in nature, if we were to one add three-dimensionality of fault structure as an additional ingredient of the system, which we have not done. We find some evidence to support this view in analysis of seismicity along the San Andreas fault.

c) seismicity is nonstationary and may be episodic, and that local periodicities cannot be invoked to predict the time of the next large event, given only the past history of such large events at one place.

d) no barrier, even of great strength, can survive forever unbroken without itself rupturing in a large earthquake.

We have constructed quasistatic planar (2-D) versions of B-K models with variable friction in elongated faults, with appropriate end conditions. We find, as in the dynamical 1-D cases, the localization of large earthquakes and of small earthquakes into non-overlapping regions.

We have begun an attack on the problem of the transverse scale-size in the B-K model. The problem here is that real earthquakes have a stress reduction in a direction transverse to faulting, a feature of importance equal to that of the stress intensification in the plane of faulting just beyond the edge of a crack. The transverse scale size is gauged either by the length of the crack or the thickness of the seismogenic zone, whichever is the smaller. But in the B-K model there is only one transverse scale size, and hence the model can only simulate interactions among events where fracture length is greater than the thickness of the seismogenic zone. For California this means that B-K models are suitable for the modeling of earthquakes with fracture lengths greater than 15 km and hence we cannot model earthquakes with approximately M<6.5. Hence the standard B-K models in

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either 1-D or 2-D are not asymptotic to elasticity on the small scale. A concerted first attempt at introducing a variable transverse scale size has shown that we must consider the possibility of amending the assumption that breaking strength and geometry are simply mapped one into the other. We are currently making an effort to construct a more realistic understanding of the nature of the relationship between geometry and friction.

We have begun a study of the relative influences of barriers and asperities on the nature of clustering. In our view, these features arise because of geometrical heterogeneity of earthquake faults. As noted, in our view these features are best represented by inhomogeneities in breaking strengths. In the one case, we imagine barriers to be large scale geometrical offsets in faults, which must represent strong obstacles to dynamical rupture. In the other, we imagine that seismicity precursory to earthquakes on the largest scale, has left the fault zone in a weakened state, which we suppose to be due to the influence of crustal fluids. As fluid or pore pressure increases, frictional strength is lowered progressively, and further fractures are ultimately triggered. In our models, asperities are the last, presumably strong, unbroken frictional contact in the interior of an otherwise weakened fracture surface. In this model the influence of fluids becomes paramount. Fractures arising from precursory seismicity remain unsutured for a time that is short compared with the time required for expressive diffusion. During this time interval, stress corrosion due to the fluid weakens the asperities and fusion among the dilatant cracks ensues. Thus the simulation depends on an understanding of the lifetime of fluids and their diffusion from cracks of different sizes. Here we have relied significantly on the pumping/valving model of Simpson for the interaction of a fault zone with fluid reservoirs in the lower crust. We have begun an investigation of the importance of healing on producing intermediate-term clustering of seismicity in 1-D B-K models. There are no results to describe as yet on this problem; we remain, at this writing, in the programming phase of the simulation. We also are considering models of percolation of fluids.

We have investigated the influence of slip weakening models in the quasistatic regime on earthquake clustering. Thus far, we have observed foreshocks and aftershocks on these models but we have not observed any significant influences on long-term evolutionary patterns. Exploration of these features is continuing.

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Annual Summary Report, Southern California Earthquake Center, USC P.O.#569928

Evaluation of the characteristic earthquake concept in Southern California

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October 1991

Studies are underway on identifying possible physical origins of characteristic earthquake response and on examining limitations to the concept. These involve projects on the *physics of earthquake sources* and on *crustal deformation.*

Physics of earthquake sources. Strong geometrical variations such as jogs or stepovers at the ends of fault segments can lead to characteristic earthquake behavior, at least for a sequence of earthquakes. However, there is much current interest in the concept that essentially uniform fault models can lead to spatio-temporally complex slip response. We are studying such possibilities in a related USGS program, using models that properly incorporate 3D elastic interactions between slip and stress distributions and which use lab based rate- and state-dependent friction laws. Here we seek to understand whether uniform fault models which show spatio-temporally complex slip can be tripped into a characteristic earthquake mode by modest variations of frictional constitutive properties or geometry along strike.

The work accomplished so far on this topic has been on computational analysis of slip on a long vertical strike-slip fault between elastically deformable crustal blocks. These are driven such that each point on the fault moves, in long-term average, at an imposed "plate" velocity. The analysis is done by boundary integral equation methods based on the Chinnery solution. Rate- and state-dependent friction applies on the fault surface, and A–B [$=Vd\tau_{ss}(V)/dV$] varies with depth, in a way specifically constrained by data on granite under hydrothermal conditions, being negative in the cool/shallow crust and positive in hot/deeper regions (V=slip speed; τ_{ss}=steady state frictional strength). At each depth, constitutive properties in the models are either uniform in the along-strike direction or are perturbed, sometimes only slightly, from uniformity. Results thus far, from simulations with sufficiently refined grids to approach the continuum limit (which, unfortunately, means large and rather slow computations, and which constrains the range of characteristic slip distances for state transitions which can be studied), suggest that uniform fault models are remarkably resistant to breakup into spatially complex slip patterns along strike. This is in interesting contrast to the conclusions which other investigators have drawn based on inherently discrete models (such as cellular automata or spring-block arrays with simplified classical friction laws, which have no well defined continuum limit upon reduction of cell or grid size).

Only limited study of the response in the presence of significant property variations along strike has yet been done and conclusions on the topic are very tentative. Nevertheless, the results show the possibility that division of a long planar fault zone into segments along strike with differences in constitutive properties, that would be consistent with, say, a two or more variation in earthquake recurrence time (if the local properties applied everywhere), may lead to phase locking of the array of segments into coordinated earthquake response, with an intermediate recurrence interval, rather than to quasi-independent characteristic behavior of the segments. If this feature is found to be general in further study, there would seem to be a strong case for the necessity of geometric obstacles to slip transmission at segment ends as a basis for characteristic earthquake response.

Crustal deformation. The aim is to apply a physical model of crustal stressing and deformation, in the interseismic period, near a locked fault zone to examine time dependence in loading of a fault segment which, at least sometimes, responds in a characteristic-like earthquake mode. The focus in the first year is on the Parkfield segment. The SCEC funds are used to share the support of a postdoc, Y. Ben-Zion, who is studying similar issues under complementary support from an NSF/EAR grant. Crustal deformation is assumed to be driven by a steady underlying shear flow in the mantle, consistent with Pacific/N. America relative motion and uniform along strike over a length scale long compared to the Parkfield segment. The elastic-brittle crust is coupled to the mantle flow through a viscoelastic lower crust, of which properties are somewhat constrained by our previous modeling of SAF geodetic data, including that from the greater Palmdale network, in work by Li and Rice (JGR,'87) and Fares and Rice (EOS,'88). (Plausible ranges for relaxation properties in the lower crust may be somewhat further constrained by our ongoing USGS supported analysis of postseismic deformation following the 1989 Loma Prieta earthquake). In the simple modeling here, in contrast to that discussed on the previous page, the fault zone is divided into locked portions, on which slip is imposed kinematically at the times of prior earthquakes, and freely slipping parts; locations are constrained by seismicity. An important consequence of the model is that the loading rate, and hence seismic behavior, of a particular fault segment is to some extent affected by its neighbors; for Parkfield, these are the regions of the 1857 (and perhaps 1906) earthquake(s), and the creeping zone to the NW. Thus the loading rate of the Parkfield patch must inevitably have some time dependence, dictated by timing and postseismic effects of prior great earthquakes. Likewise, the NW end of the 1857 segment should be affected by Parkfield ruptures.

3D finite element calculations are employed to model such interactions. The model most extensively studied so far consists of a 17.5 km elastic upper crust, a 7.5 km viscoelastic lower crust, and a stiffer and more viscous viscoelastic upper mantle. The crust has a single vertical fault plane extending to the top of the mantle. That plane is locked against slip, except in great earthquakes, over the top 12.5 km in zones along strike corresponding to the 1857 and 1906 events. Free-slip boundary conditions are imposed on the fault plane below those locked rupture zones and everywhere in the creeping region between them. An imposed constant far-field shear motion at 35 mm/yr and periodic 1906- and 1857-type earthquakes generate slip rates along the creeping fault segment that show non-uniformity in time. Shortly after an adjacent great earthquake, slip rates in the creeping zone are higher than the far field velocity, while later in the cycle they are lower. If Parkfield earthquakes are a response to this time dependent loading, their recurrence interval would tend to lengthen with time since the 1857 event. Thus, an underlying hypothesis of characteristic periodic earthquakes at Parkfield may not provide the best estimate of the occurrence time of the next event. For example, using the statistics of past events we find that if Parkfield earthquakes are responses accumulated slip deficits near Middle Mountain, the next event would be predicted for about 1992 ± 9 yr if the lower crust relaxation time is 15 yr, and 1995 ± 11 yr for lower crust relaxation time 7.5 yr, rather then the 1988 ± 7 yr estimate based on periodicity in time. These relaxation times are consistent with the range, albeit poorly constrained, found in fitting other geodetic data along the San Andreas system, the range being about 1 to 2 yr per km of thickness assumed for the relaxing layer (only the ratio of relaxation time to layer thickness, and neither independently, is of significant influence on the time dependent surface straining predicted by models of the type examined).

Future extensions are envisioned to analyze interactions of other possibly characteristic fault segments with their neighbors.

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1991 SCEC Progress Report of Bruce Shaw

My research this past year has centered on trying to make connections between very simple dynamical models of an earthquake fault, and seismological observations. The foundation of the modeling is a one dimensional homogeneous deterministic partial differential equation with the minimal ingredients of an elastic coupling, a loading mechanism, and a frictional instability. The simplest discretization of the equation gives the classic model in seismology of Burridge and Knopoff. This is the model we study numerically. I have been developing ways of measuring the model in order to compare it with seismological observations. These measurements include examining the small event activity preceding large events, studying the average moment spectra for events of different sizes, and plotting relations between various source parameters. I have been studying various parameter regimes of the friction function, and examining the behaviors of the model in these different regimes.

One of the things missing from the simplest model is aftershocks– there is only a rupture timescale and a loading timescale. To add a new timescale which produces foreshock and aftershock clustering, I have developed a generalization of the model which couples the displacement field to a new diffusing field. I obtain Omori's law analytically and numerically. I have begun to study the spatial and temporal distribution of aftershocks in real earthquake catalogues to try to test this model.

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Southern California Earthquake Center
Research Summary, 1991

Application of Models of Dynamical Systems to Seismicity, Earthquake Patterns and Predictions

P.I., C.H. Scholz, Lamont-Doherty Geological Observatory, Columbia Univ.

1. Study of a quasi-static block slider model.

We have been studying a 2-D block slider model similar to that of Brown et al (1991), and have reached two main conclusions. The first is that the behavior of this class of models is strongly dependent on model parameters, namely the ratio of Cr, the critical value, vs. the spring stiffnesses. Results for the case with the spring stiffnesses $K_{coupling}/K_{pulling}$ =50 are shown in Fig. 1a. At some values of Cr the model behaves in a way analogous to steady-state creep (Cr=610); there are no whole array events and the cumulative event size distribution is exponential. At other values (e.g. Cr=590), the behavior is dominated by events that break the entire grid. It is only at the transitions between these two (e.g. Cr=600) that we find power law distributions.

The second conclusion is more serious. For earthquakes, stress drop is scale independent, so mean slip scales with rupture dimension L. This means that moment, M_o should scale with L^2 in 1-D models and with L^3 in 2-D models. However, in our 2-D model, M_o scales linearly with area (Fig. 1b), meaning that slip is scale independent (it is controlled by the coupling spring constant). A crossover phenomenon begins at about Area=200 and settles down at about Area=400 to another linear region with a higher slip. This crossover corresponds to a change in dominance of scaling from the coupling to the pulling springs. We believe that this scaling problem is common to all spring slider models, both dynamic and quasi-static, that are now being studied. It is caused by a lack of long-range interactions.

Ref. : Brown, S.R., Scholz, C.H., and Rundle, J.B., A simplified spring-block model of earthquakes, Geophys. Res. Lett. **18**, 215-218, 1991.

2. Study of Earthquakes as SOC phenomena.

The second part of our work concerns the study of those observations of earthquakes and faulting that are relevent to the argument that this system is one that exhibits self-organized critical (SOC) behavior. Two studies have been completed and reported in papers now in press. In the first (Scholz, 1991) the properties of earthquakes and faults were reviewed with this question in mind. Both were shown to obey self-similar scaling laws, have fractal size distributions, and internal fractal irregularity. However, in contrast to models, the natural system contains a characteristic dimension, the seismogenic thickness, that profoundly effects the behavior. In the case of earthquakes, *small* earthquakes, those below this dimension, obey different scaling laws than *large* earthquakes, larger than this size. They consequently belong to different fractal sets and have different size distributions.

In the second paper (Pacheco et al, 1991), this difference in the size distribution between small and large earthquakes was specifically tested using a new global earthquake catalogue which had been corrected for problems with the magnitude scale and tested for completeness. Both show a cumulative size distribution that is a power law, $N(M_o) = aM_o^{-B}$, where B=2/3 for small earthquakes and B=1 for large earthquakes. The crossover is at M_s=7.5 for subduction zone events (L~60km) and M_s=6 for transform faults (L~10km) (Fig.2). The recognition of this distinction has profound implication for earthquake hazard analysis.

SCEC supported publications.

Scholz, C.H., Earthquakes and faulting: self-organized critical phenomena with a characteristic dimension., In *Proc. NATO A.S.I.*, *Spontaneous Formation of Space-time Structures and Criticality,* (T. Riste and D. Sherrington, eds.), Kluwer, Dortrect, in press, 1991.

Pacheco, J., Scholz, C.H. and Sykes, L.R., Changes in frequency-size relationships form small to large earthquakes, *Nature,* in press, 1991.

G-19

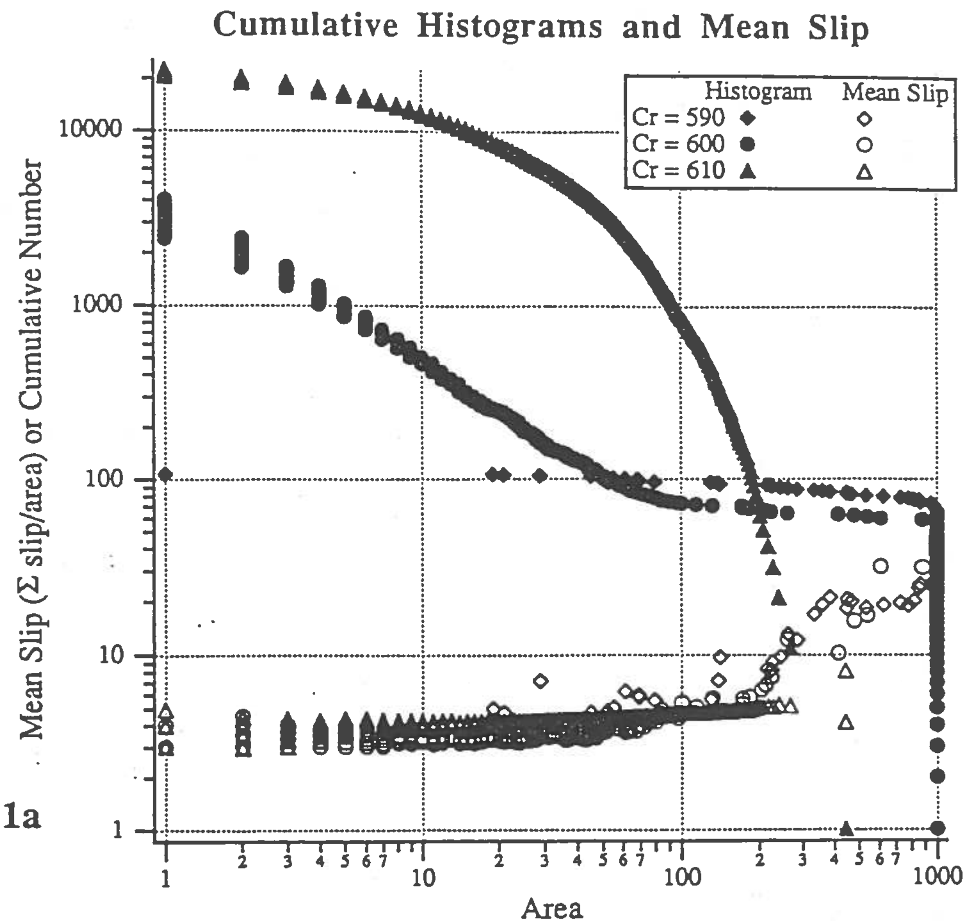

Figure 1a

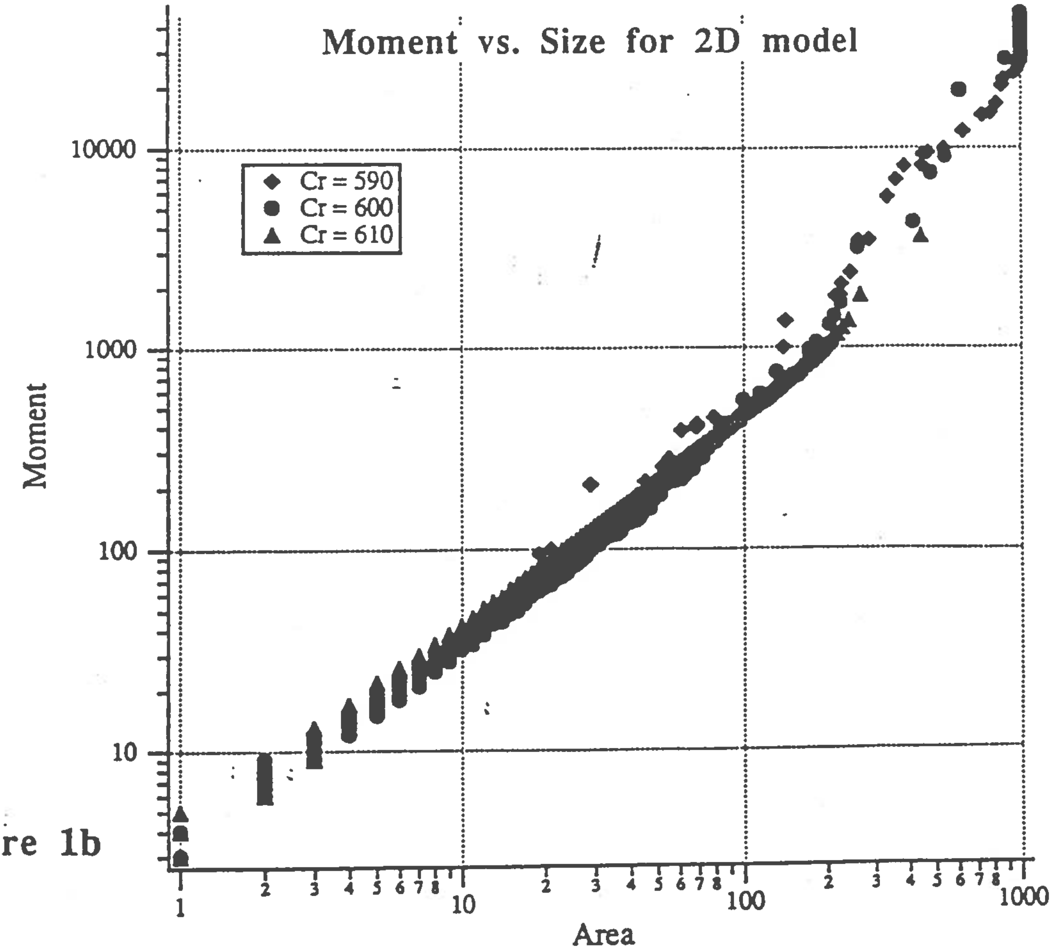

Figure 1b

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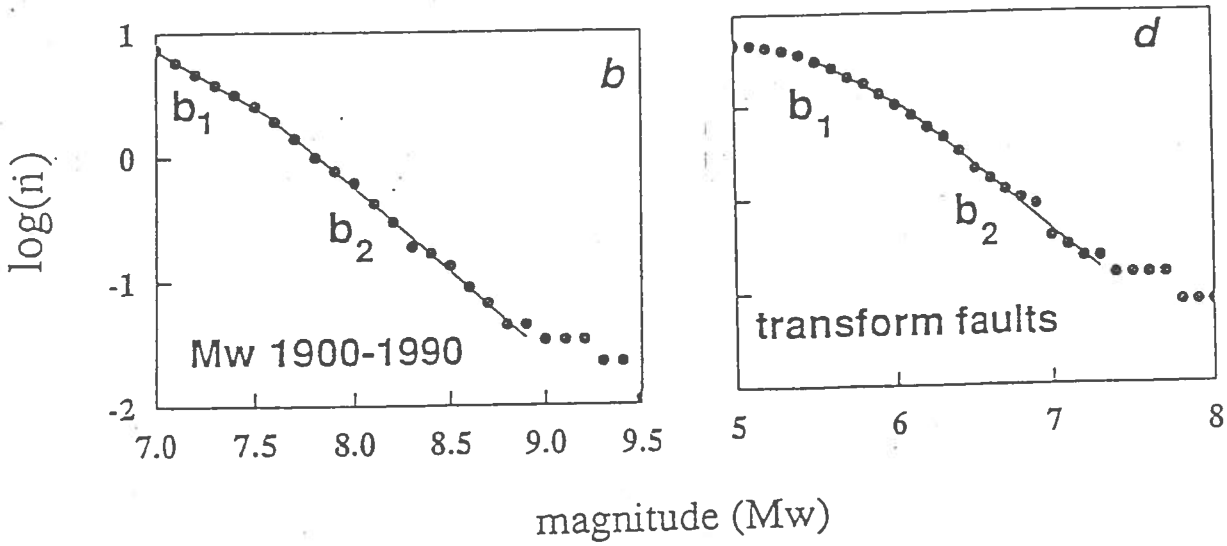

1
0
-1
-2
log(n)
b
b1
b2
Mw 1900-1990
7.0
7.5
8.0
8.5
9.0
9.5
d
b1
b2
transform faults
5
6
7
8
magnitude (Mw)

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T.LEVSHINA

1991 ANNUAL SUMMARY REPORT

I have been working for SCEC since July,8 1991. During this period the following has been done:

1.Software, designed in the International Institute of Earthquake Prediction under supervision of prof.V.I.Keilis-Borok, has been installed on the UCLA VAX. This software allows for the processing of catalogues of earthquakes to perform various tasks as sorting, merging and selection of data. In addition it executes the algorithm of earthquake prediction CN [1]. We have begun a study of the spatial distribution of those intermediate-sized earthquakes that have triggered retrospective alarm under algorithm CN.

2.I continue to work on the problem of recognition of the possibility of reoccurrence of a strong shock in a focal zone of a strong earthquake. Since this work started in 1990 in collaboration with I.Vorobieva, the recognition algorithm has been developed and some results have been obtained. Now the stability of these results with respect to the variation of initial parameters are being tested. The algorithm has been successfully applied to some new seismic regions. I am going to test the algorithm and compare previous results with the results which will be obtained from a study of aftershock sequences of strong earthquakes of the Pacific seismic belt.

3.I started the new work under supervision of prof.L.Knopoff. This work correlates with numerous works, where the fractal behaviour of earthquake flow has been investigated. The idea is to use a modification of the methods of Grassberger and Procaccia [2], originally proposed for the investigation of dissipative nonlinear dynamical systems. They have proposed a measure (correlation exponent) of the local structure of strange attractors toward which these systems will tend. We are trying to apply this approach to the seismic process, even though it is unclear what kind of nonlinear system this process might be. We assume that even though the seismic process can be modeled as a nonlinear dissipative dynamical system with a large or even an infinite number of degrees of freedom, it may nevertheless possess a low-dimensional attractor. In order to obtain the correlation exponent of this attractor we embed the attractor in a higher dimensional space, thus far using a single-variable time series. By analyzing the behavior of correlation integral we hope to determine whether the correlation arises due to deterministic chaos or due to random noise. We are considering the earthquakes with magnitude $M \geq 4$ on the San Andreas fault, since 1965. Some preliminary results have been obtained.

1.V.I.Kelis-Borok,L.Knopoff,I.M.Rotwain and C.R.Allen. "Intermediate-term prediction of occurrence times of strong earthquakes" ,Nature, vol.335, 1988,690-694.

2.P.Grassberger and I.Procaccia. "Measuring the strangeness of strange attractors" Physica 9D (1983),189-208.

Group H: Engineering Applications

Group Leader: Geoff Martin

Research Program to be Initiated Early in 1992

H-1

A RESEARCH PROJECT BETWEEN THE

SOUTHERN CALIFORNIA EARTHQUAKE CENTER

AND

- CALIFORNIA DEPARTMENT OF TRANSPORTATION
- CITY OF LOS ANGELES DEPARTMENT OF PUBLIC WORKS
- LOS ANGELES COUNTY DEPARTMENT OF PUBLIC WORKS

FOR A JOINT PROGRAM ON

THE CHARACTERISTICS OF EARTHQUAKE GROUND MOTIONS FOR SEISMIC DESIGN

I. BACKGROUND

The California Department of Transportation and the City and County of Los Angeles, all presently have major design or seismic retrofit programs related to the development and improvement of their bridge infrastructures. Historically, bridges have proven to be very vulnerable to earthquakes, sustaining damage to both superstructures and foundations, and in some cases have been totally destroyed. The 1971 San Fernando earthquake damaged more than 60 bridges on the Golden State Freeway in California. The cost to the State for repair, including indirect costs due to bridge closures, was approximately $100 million. The 1989 Loma Prieta earthquake damaged more than 80 bridges and caused the deaths of more than 40 people. The costs of repair (not including indirect costs) have been estimated at between $1.8 and $2.0 billion.

The specification of earthquake ground motion characteristics play a critical role in establishing seismic design codes for both bridges and other structures. Both the California Department of Transportation (Caltrans) and the AASHTO Guide specifications for seismic design use smoothed acceleration response spectra keyed to peak ground acceleration maps to characterize ground motions. The shape of spectra also reflects site soil classifications. With increasing costs of bridge construction and the need for seismic retrofit of a large number of older bridges in California, it is clear that research focused on increasing confidence levels and optimizing earthquake ground motion characteristics for design is of paramount importance.

With the above objective in mind, design engineers with Caltrans and the City and County of Los Angeles (to be designated C^3) have jointly agreed to sponsor a three year research program through the Southern California Earthquake Center (SCEC). A tentative list of research tasks was initially proposed by Caltrans, and was the subject of joint discussions between representatives of C^3 and SCEC at a meeting in Los Angeles on March 30, 1991. Further discussions to refine and prioritize research tasks were held during a one day workshop at the University of Southern California on May 22, 1991.

II. SOUTHERN CALIFORNIA EARTHQUAKE CENTER

In February 1991, the National Science Foundation and the U.S. Geological Survey designated the University of Southern California as the focal point for a new

Southern California Earthquake Center. The center includes USC, Caltech, UCLA, UC Santa Barbara, UC Santa Cruz, UC San Diego (Scripps Institution of Oceanography), Columbia University (Lamont-Doherty Geological Observatory) and the USGS. Keiiti Aki, holder of the W.M. Keck Foundation Chair in Geological Sciences at USC and a member of the National Academy of Sciences, is the Science Director, and Thomas Henyey, Professor and former chairman of the USC Department of Geological Sciences, is the Executive Director. Thomas Heaton, chief scientist of the USGS office in Pasadena, coordinates his agency's involvement in the center.

SCEC has received more than $5 million for the first year from the NSF and the USGS. The program is expected to last at least five years and potentially as long as 11 years. Funds are being used for scientific research at the eight participating organizations and for establishing a major earthquake data and information center in Southern California. Scientists from several other universities and the California Division of Mines and Geology are also participating in the SCEC research effort.

The principal task of SCEC is the development of a "master model," or framework for estimating seismic hazards in Southern California. This model will combine existing knowledge of earthquakes with new knowledge to be gained through additional research. It will represent a scientific consensus as to what can be expected from future earthquakes in Southern California. Research areas identified as important to developing a master model for Southern California include the history of fault movements and statistics of past earthquake occurrences, the regional pattern of strain buildup, the physical properties of earthquake sources, and how the surface of the earth, given its geological diversity, shakes in response to seismic waves generated by earthquakes.

Participating co-investigators from SCEC institutions are shown in Table A-1 appended. Research tasks sponsored by the NSF and USGS are structured under seven major working group headings, each with a group leader or coordinator as shown in Table 1. An eighth group (Group H -- Engineering Applications) was recently added to reflect the need for coordinating products of scientific research with the needs of the engineering design profession, and includes civil engineering faculty members from participating institutions. These groups function within the organization structure shown in Table 2. The C^3 research program will be coordinated and managed by the Assistant Director, Engineering Applications (Dr. Geoffrey R. Martin).

III. RESEARCH TASKS

From the results of the C^3/SCEC workshop held at the University of Southern California on May 22, 1991, a research program comprising 9 research topics has been identified for year 1. Further discussion of each of the tasks is given below.

Task H-1: Characteristics of Earthquake Response Spectra in Southern California

Co PIs: Dr. V. Lee and Dr. M. Trifunac, University of Southern California

Smoothed elastic response spectra are the cornerstone of seismic design procedures. Existing smoothed spectral shapes and site correction factors used in design guidelines or codes, have been determined from a limited data base, with shapes being keyed to estimates of peak ground acceleration. In this three year research program, a systematic evaluation of response spectra for over 1,000 Southern California strong motion acceleration records will be undertaken. These records cover the period 1933 to the present, and are on file in the USC Civil Engineering Department Strong-Motion Earthquake Data Information System (EQUINFOS).

The evaluation will take the form of regression analyses of spectral amplitudes to develop empirical scaling coefficients reflecting the effects of earthquake magnitude, epicentral distance, and site parameters (rock, stiff soil sites and deep soil sites). The evaluations will also include the development of frequency dependent attenuation relations for use in regression analyses. Hence, spectral scaling functions will be frequency dependent and cover periods between 0.04 to 15 seconds. The program will encompass:

- Finalizing the available data base on site characteristics for sites where strong motion data has been recorded (coordinated with Task H-5)
- Digitizing and processing the several hundred records which have yet to be subjected to the corrections for instrument frequency response and baseline adjustment (including the Whittier earthquake aftershocks, and records from the recent Pasadena, Malibu, Upland, and Sierra Madre earthquakes obtained by the 81 strong motion accelerograph stations operated by the USC Civil Engineering Department under the direction of Dr. Trifunac).
- Generating 5% damped elastic response spectra for newly processed earthquake data.
- Carrying out detailed analysis of the frequency dependent attenuation equations for spectral amplitudes using the complete earthquake data base (these attenuation relations will subsequently be used for Task H-7).
- Running all required regression analyses to determine frequency dependent scaling relations for spectral amplitudes.
- Writing progress reports and a final report.

The results of the project will provide the means for re-assessing the manner in which deterministic smoothed response spectra can be optimized for design and code use. The database will also provide a unique resource for research on topics such as studies of local site response using wave propagation analysis, and seismic hazard evaluations. All processed data in EQUINFOS will be available to C^3 engineers for either research or design use.

<u>Task H-2:</u> <u>Southern California Fault and Earthquake Parameters</u>

<u>Co PIs:</u> Dr. K. Sieh and Dr. E. Hauksson, California Institute of Technology

The assessment of the maximum earthquake magnitude a fault is capable of and the recurrence relationship (fault magnitude vs. number of events per year) are

H-4

critical parameters for the assessment of the maximum credible levels of ground shaking at a given site and levels of ground shaking expressed in probabilistic terms. Ongoing research is continually modifying expert opinion on the values of these parameters and often differences of opinion develop.

The objective of this research task is to develop a consensus of professional opinion among those SCEC scientists involved in Southern California fault studies, expressed in the form of a fault map with an associated commentary. Research funds will be used to sponsor regular workshops to focus opinions and issues, to sponsor added research tasks where seen desirable, and to prepare required maps and commentary. The designed Co-PIs will provide the direction and needed coordination for this task.

Task H-3: Effects of Local Site Characteristics on Ground Accelerations

Co PIs: Dr. K. Aki and Dr. G. R. Martin, University of Southern California

Site Characteristics (depths and type of soil stratigraphy) are known to influence the intensity and frequency characteristics of ground shaking. Current design codes reflect this in the empirical manner. Whereas task H-1 will refine the nature of empirical correlations, to complement the empirical approach, more fundamental wave propagation research studies continue to be needed to fully understand site effects. These studies range from source-site modelling to separate out source and geological effects, to one dimensional site response analyses to understand the effects of soil-non-linearity on site response.

The objective of this research task is to systematically study site effects at three selected strong motion stations in Southern California, where site soil conditions are or can be readily defined. Funding will be used to install broad band seismometers at the stations to allow comparisons between characteristics of regularly occurring weak earthquake motions with those of past strong motion recordings. Source-site wave propagation studies and linear elastic and non-linear one dimensional analyses will also be conducted. Results of on-going similar research studies in Northern California sponsored by the USGS and NSF following the Loma Prieta earthquake, will also be monitored.

Task H-4: Duration of Strong Motion Shaking in Southern California

Co PIs: Dr. M. Trifunac and Dr. V. Lee, University of Southern California

The duration of strong ground motion is one of the principal earthquake characterizing parameters, and plays a major role in governing the extent of damage to structures. The failure of different structural components, depends on the number of times and the extent to which the linear response range has been exceeded. Hence, it is essential to have an adequate description of not only the largest, but of all the peaks of response.

H-5

In this task, the duration of strong motion will be defined as that portion of the accelerogram which contributes 90% of all energy available for excitation of linear structures. This definition was proposed by Trifunac and Brady in 1975, and over the period 1975-82, used to progressively develop empirical equations between duration, magnitude, epicentral distance and site geology by utilizing the available earthquake data at that time. For this study, the research will utilize the expanded data base described in Task H-1, and will encompass:

- Generation of band-pass filtered data to describe the frequency components making up the strong motion duration.
- Performance of regression analyses on the frequency dependent duration components for scaling in terms of source magnitude, epicentral distance and site conditions.
- A comprehensive final report.

Results from the project will provide the means for assessing the magnitude and number of strong motion pulses in any frequency band for a given site and design earthquake. This in turn will provide the basis for assessing the appropriate means for including duration as an important seismic design parameter in design guidelines or codes.

Task H-5: Geotechnical Site Data Base for Southern California

Co PIs: Dr. Vucetic (UCLA) and Dr. G. R. Martin (USC)

Site soil conditions, expressed in terms of soil stratigraphy which is defined by soil classification and shear wave velocity profiles, form an essential component of research on the effects of site response from earthquake ground motions. (Tasks H-1, H-3 and H-4). Such site data expressed in simplified category form (e.g., rock, stiff soil, deep soil profiles, soft soil site, etc.) also play a role in existing seismic design codes.

A large data base on site shear wave velocity profiles in southern California exists in a variety of open file publications and consultants reports. Some of these data are associated with strong motion accelerograph station sites. Additional synthetic shear wave velocity profiles have been generated from correlations with geotechnical data such as standard penetration blow counts.

The objective of this research task, is to systematically collect and catalog these data, which will ultimately form a data file in the planned SCEC geographic information system. Additional synthetic shear wave velocity profiles will be generated from collected borehole and cone penetrometer geotechnical data at selected locations. Particular attention will be focused on key strong motion instrument locations which lack site profile data. For these sites, shear wave velocity profiles will be generated by either extrapolation from nearby sites, or through direct field measurements using a "seismic" cone penetrometer.

H-6

Task H-6: Evaluation of Bridge Damage in Recent Earthquakes

Co PIs: Dr. J. Hall and Dr. R. Scott (Caltech)

Whereas bridge damage resulting from strong earthquakes in the U.S. (Alaska, San Fernando, Loma Prieta) has been the subject of extensive study, lessons learned from damage occurring in many overseas earthquakes have not been studied to the same degree. Observed structural damage to older bridges in particular, when correlated with the levels of ground shaking, can provide a significant database to aid in the development of performance criteria for the seismic retrofit of existing bridges.

In this research task, recent case histories of earthquake damage to bridges in Japan and New Zealand, in particular, will be assessed in terms of the causes of damage and the associated levels of ground shaking (estimated or recorded ground acceleration time histories). It is anticipated that much of the information can be collected through correspondence and personal telephone calls to known overseas researchers and pertinent agencies. However, personal discussions and site visits to evaluate case histories in more detail, may be warranted. Results of research will be documented in a final report.

Task H-7: Probabilistic Evaluation of Response Spectra (Uniform Risk) and Earthquake Time Histories for Southern California

Design earthquake response spectra, such as those specified by the AASHTO bridge code, are often keyed to a particular level of risk. Standard spectral shapes in the AASHTO code for example, are keyed to maximum ground accelerators with a 90% chance of not being exceeded in 50 years. Revised building seismic design codes now being considered by the National Earthquake Hazards Reduction Program, are moving towards defining response spectra in terms of spectral ordinates with uniform risk levels. In this approach, in addition to requiring maximum earthquake magnitudes and recurrence relationships for specific faults or seismo-tectonic zones, attenuation relations for spectral ordinates are required.

This research task is proposed to be initiated in year 2, and will draw heavily from the results of Tasks H-1 and H-2. The objectives will be to assess the characteristics of uniform risk spectra for seismotectonic zones in Southern California (for selected risk levels) and compare shapes and magnitudes with spectra developed deterministically. In addition, studies will be made of probabilistic techniques for the development of artificial time histories for use in design.

Task H-8: Liquefaction Characteristics and Potential of Southern California Sites

Earthquake induced liquefaction of saturated cohesionless soils has resulted in major damage to bridges and other structures during past earthquakes. Maps showing liquefaction potential (in an empirical manner) for a number of regions in southern California have been prepared by various agencies (CDMG reports, City of San Bernardino, etc.), and site specific investigation techniques to evaluate liquefaction potential more precisely, are routinely used. Numerous research studies sponsored by the NSF and USGS are currently in progress to improve predictive methods and to establish methods to evaluate post-liquefaction ground deformations.

The proposed objective of this task (commencing in year 2) will be re-evaluate the existing southern California liquefaction potential maps to take into account more recent information regarding site conditions, and to develop a more quantitative approach for assessment of post liquefaction ground deformation potential suitable for mapping, using the results of ongoing NSF sponsored research.

Task H-9: Characteristics of Vertical Ground Accelerations

Seismic design codes primarily address horizontal earthquake ground motions to determine seismic loads for structural design. However, in some cases, the effects of vertical accelerations may be significant. The objective of this task (commencing in year 3) will be to study the frequency and amplitude characteristics of response spectra for the vertical acceleration components of accelerograph records in southern California. Comparisons will be made with response spectra for horizontal components, and recommendations made for methods to include vertical acceleration design criteria in design codes.

IV. PROGRAM COORDINATION AND MANAGEMENT

The overall research program will be coordinated and managed by Dr. Geoffrey R. Martin, SCEC Assistant Director for Engineering Applications. The designated SCEC Principal Investigators for each of the research tasks, have been selected and invited to participate in the program because of their expertise and experience in the topic areas. They will be responsible for the technical direction and reporting for their particular tasks.

To ensure that relevant results of related research being conducted in other NSF/USGS sponsored SCEC research groups is integrated into C^3 research, task review committees will be established for each task from the SCEC scientific pool. Committees will comprise the Task PI(s), invited SCEC scientists/engineers, and the Assistant Director for Engineering Applications. Review committees will meet quarterly to monitor progress, make suggestions on research directions, and provide integration with other SCEC activities.

Dr. Martin will be the principal interface between SCEC and C^3 technical and administrative representatives, and will prepare quarterly progress reports.