



SOUTHERN CALIFORNIA EARTHQUAKE CENTER



UNIVERSITY
OF SOUTHERN
CALIFORNIA

Southern California Earthquake Center



CALIFORNIA
INSTITUTE OF
TECHNOLOGY

1997 Annual Meeting



LAMONT-DOHERTY
EARTH OBSERVATORY
OF COLUMBIA
UNIVERSITY

October 4-7, 1997



UCLA



U.C. SAN DIEGO,
SCRIPPS INSTITUTION
OF OCEANOGRAPHY

Doubletree Hotel
Costa Mesa, California



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1997 SCEC ANNUAL MEETING AGENDA

Saturday, October 4

- 11:00 a.m.** SCEC Standing Committee on Electronics Communications
- 1:00 p.m.** SCEC Steering Committee
- 5:00 p.m.** Earthquakes and Insurance

Sunday, October 5

- 10:00 a.m.** Field Trip led by Lisa Grant, Karl Mueller, Eldon Gath and Roz Munro
"The Geomorphic and Structural Analysis of the San Joaquin Hills in Orange County, California"
- 12:00 p.m.** Knowledge Transfer Planning Meeting
- 6:00 p.m.** Icebreaker and Dinner
- 7:15 p.m.** Poster Session (Posters remain available until Tuesday noon)
- 8:30 p.m.** Advisory Council Meeting with presentations by Andrews and Abdouch on KT/Education Programs
- 8:30 p.m.** Meeting of SCIGN Coordinating Board

Monday, October 6

8:00 a.m. Session I: Plenary Session

Welcome and Introduction
SCEC Science Program: Where Are We and Where Are We Going?
The SCIGN Project
Report of Knowledge Transfer and Education

Heney (20)
Jackson (30)
Bock (20)
Andrews (15)
Abdouch (15)

Break (9:40 to 10:00)

Short Research Reports from Group Leaders

Day (15)
Sieh (15)
Clayton (15)
Hudnut (15)
Knopoff (15)

11:15 Phase III Report Presentation

Dave Jackson	Introduction
Dave Jackson	Seismic Source Models
Steve Park	Estimation of Shear Wave Velocities and Site Classifications
Kim Olsen	Site Amplification in the Los Angeles Basin from 3-D Modeling of Ground Motion
Jamie Steidl	Site Response Studies
John Anderson/Yajie Lee	Evaluation of Empirical Attenuation Relations
Norm Abrahamson	Hazard Calculations
Norm Abrahamson	Strong Motion Seismograms for Scenario Earthquakes
Norm Abrahamson	Conclusions

Lunch @ 12:45 p.m.

Session II: Working Group Meetings

Posters Available During These Sessions

Note: There will be no group meeting for education and outreach. Jill and Curt will hold separate sessions with invited scientists to develop Knowledge Transfer/Education RFP.

1:45 to 3:15 p.m.	Group A:	Jackson
3:15 to 4:45 p.m.	Group B:	Day
4:45 to 6:15 p.m.	Groups C and G:	Sieh Knopoff

Dinner at 6:15 p.m.

Dinner Speaker: Arch Johnston of CER/Memphis; **Title of Talk:** Dissecting the New Madrid Earthquakes

7:45 p.m.	Groups D and F:	Clayton Hauksson
9:15 p.m.	Group E	Hudnut

Tuesday, October 7

8:00 to Noon SCEC II: The Future Proposal Henyey
Note: Colleagues from Northern California will be invited to the meeting.

End of SCEC Meeting

Lunch @ 12:00 p.m. for SCEC Advisory Council and Steering Committee
Advisory Council meets in Executive Session after lunch.

1:00 p.m.	ROSRINE Meeting	Schneider
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1997 SCEC ANNUAL MEETING PARTICIPANTS

Curt Abdouch	USC
Mark Abinante	UCLA
Norm Abrahamson	Pacific Gas and Electric
Graeme Aggett	USC
Duncan Agnew	UC-San Diego
Kei Aki	USC
Carmen Alex	UC-Santa Barbara
Greg Anderson	UC-San Diego
John Anderson	Nevada-Reno
Jill Andrews	USC
Ralph Archuleta	UC-Santa Barbara
Ramon Arrowsmith	Arizona State
Luciana Astiz	UCSD
Shirley Baher	UCLA
Gerald Bawden	UC-Davis
Jeff Beard	USC
Eric Bender	Orange Coast College
Mark Benthien	USC
Yehuda Ben-Zion	USC
Jacobo Bielak	Carnegie-Mellon
Adam Bielecki	Colorado
Tom Bjorklund	Houston
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Yehuda Bock	UC-San Diego
Fabian Bonilla	UC-Santa Barbara
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Pierfrancesco Burrato	Oregon State
Bill Bryant	CDMG
Jim Brune	Nevada-Reno
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Cheryl Contopulos	Caltech
Anne Cooper	Tritan Research
Allin Cornell	Stanford
C.B. Crouse	Dames and Moore
Wendy Dailey	Cal Poly-Pomona
George Davis	Arizona
Jim Davis	CDMG
Paul Davis	UC-Los Angeles
Steve Day	San Diego State
Jeff Dean	UC-San Diego

Robert DeMarco	National Seismic Survey/Italy
Jishu Deng	Caltech
Jim Dieterich	USGS-Menlo Park
Jim Dolan	USC
Danan Dong	JPL
Andrea Donnellan	JPL
Don D'Onofrio	National Geodetic Survey
Macon Doroudian	UCLA
John Eichelberger	Alaska
Leo Eisner	Caltech
Ned Field	USC
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Kathryn Hanson	Geomatrix
Jeanne Hardebeck	Caltech
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Tom Heaton	Caltech
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Mandy Johnson
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Lucy Jones
Yan Kagan
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SCEC ORGANIZATION - 1997

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Director for Education: Curtis D. Abdouch
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Director for Knowledge Transfer: Jill H. Andrews
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Board of Directors

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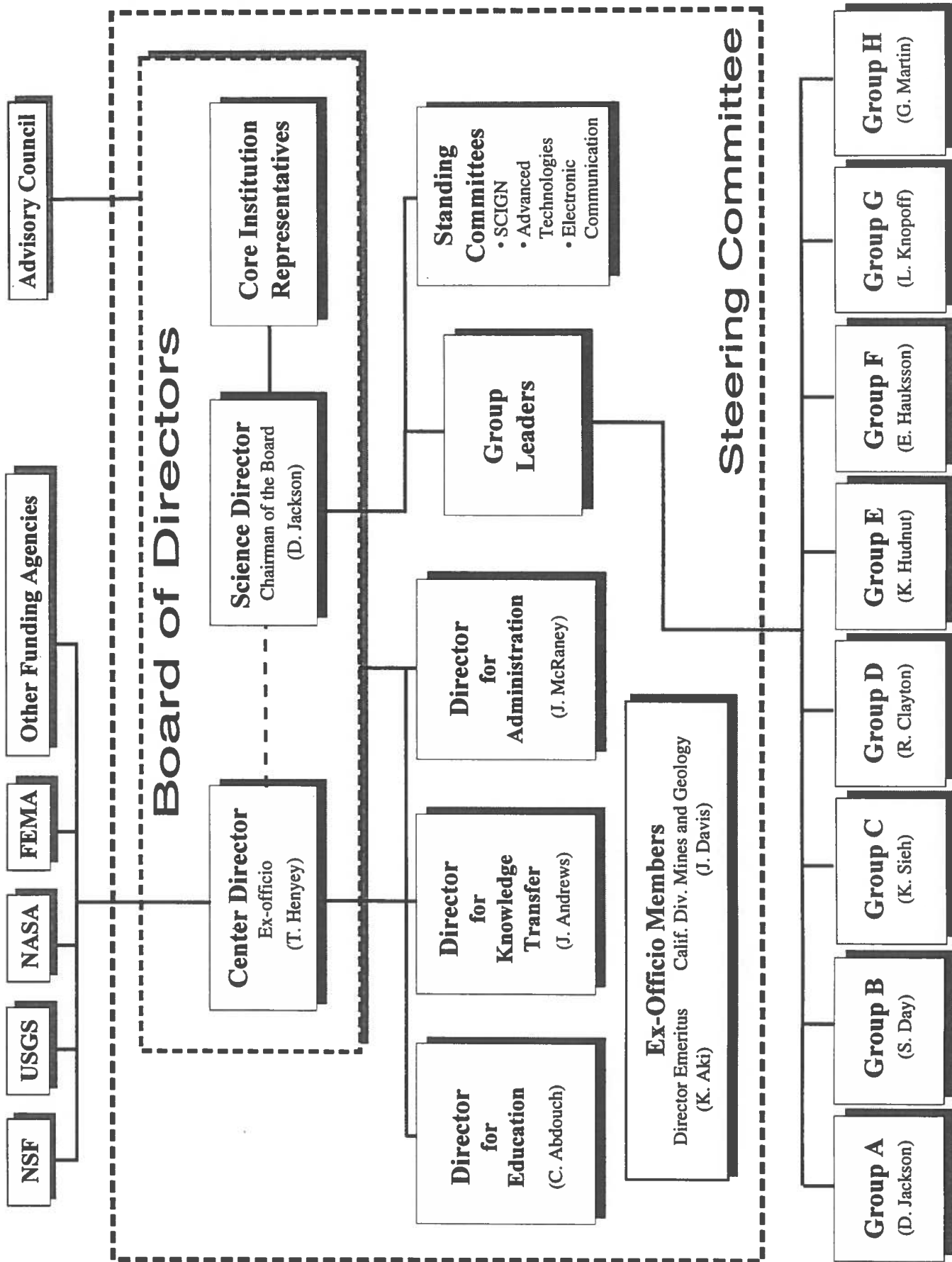
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Research Group Leaders

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B: Strong Motion Prediction:	Steve Day San Diego State University
C: Earthquake Geology:	Kerry Sieh California Institute of Technology
D/F: Subsurface Imaging and Tectonics and Seismicity and Source Parameters:	Robert Clayton California Institute of Technology
E: Crustal Deformation:	Kenneth Hudnut United States Geological Survey
G: Earthquake Source Physics:	Leon Knopoff University of California, Los Angeles

Steering Committee Members (ex-officio)

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CICISE/Ensenada, Mexico

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Paris, France

Juan Madrid

Geoffrey King

SCEC Science Director Annual Report

Dave Jackson

University of California, Los Angeles

Accomplishments and Challenges

Following a year of significant accomplishments, the Southern California Earthquake Center faces momentous decisions in the next. Here I highlight just a few.

Our education and knowledge transfer programs continue to provide outstanding communication between earthquake scientists and information users. The Center has become the place to go for detailed and trustworthy information on earthquake hazards. In 1996 we organized a successful workshop on Earthquake Vulnerability, sponsored by the City of Los Angeles. We are now collaborating with the City and the Structural Engineers Association of Southern California to develop the scientific basis for policy guidelines relating to non-ductile concrete buildings and multi-family residences with "tuck-under parking." These building types present particular concerns to the city, and they merit separate consideration because the types of ground motions and soil conditions that cause most damage vary from one building type to another.

The "Phase III" report on seismic hazards in southern California is nearing completion. The report will feature a range of seismic source models to illustrate the effects of basic scientific uncertainty; calculation of theoretical seismograms ("time histories") for realistic scenario earthquakes; a treatment of the amplification caused by three dimensional wave propagation in sedimentary basins; and a thorough analysis of site effects on peak acceleration, spectral acceleration, and velocity. The report presents testable scientific models, leaving the task of actual hazard estimation to the government agencies charged with this responsibility.

There is good news and bad news. The apparent discrepancies between observed and predicted earthquake rates, reported in Phase II, can be partly resolved by allowing for multi-segment earthquakes on the principal faults. However, sophisticated modeling of site effects has failed to explain the scatter of measured strong accelerations. Furthermore, credible earthquakes in the Los Angeles basin could cause devastating ground motions, with peak spectral velocities on the order of 1 m/s for periods around 1 second.

We've made great progress in crustal deformation studies. The first generation deformation velocity map, based largely on Global Positioning System data, was unveiled last year at the annual meeting. Since then the map has been published in EOS, and a strain rate map derived from it has been published as a Perspective in Science. The strain rate map shows a dramatic surprise: postseismic effects dominate the strain rate pattern, and effects of earthquakes in 1992, 1979, 1952, and 1940 are still occurring.

Interdisciplinary research is a high priority at the Center, and several collaborations between working groups are bearing fruit. The strong-motion, geology, and seismic imaging groups are collaborating on a unified 3-D seismic velocity model for southern California. The model will be invaluable for computing theoretical seismograms. The master model, crustal deformation, and seismic imaging groups all collaborated in a joint workshop on earthquake stress interactions at Menlo Park. A special edition of the Journal of Geophysical Research highlighting this work is well on its way to publication.

The Center will continue to focus strongly on stress perturbations from earthquakes. The effect of seismic stress perturbations on earthquake probabilities is especially important as it is the leading hypothesis to explain temporal variations in earthquake rates. We will continue to

develop the "physical master model" of stress evolution. This model will include stress perturbations from moderate and large earthquakes, tectonic stress accumulation, and viscoelastic stress relaxation. The model will benefit greatly from our geological measurement of fault slip rates and displacement patterns of past earthquakes; a new catalog of earthquake focal mechanisms estimated using our 3-D seismic velocity model; and geodetically measured deformation velocities.

The Phase II report documented serious discrepancies between observed deformation velocities and those predicted by the Phase II fault slip model. The new deformation velocity map makes these discrepancies even more prominent. Strain is much more diffuse, and much more strongly affected by past earthquakes, than predicted by the fault model. We don't yet have a deformation model that agrees adequately with both geodetic and geologic data. Clearly we need such a model.

Theoretical seismograms will surely be the foundation of seismic hazard analysis in the future. At the Center we've come a long way to developing capabilities for accurate calculations. We need to build a self-consistent model that includes three dimensional wave propagation, non-linear site effects, and rupture models for all past earthquakes above a moderate magnitude threshold. We need to calibrate this model using all available data for suitable earthquakes. For the immediate future we'll try to fit available seismograms at 3 seconds and longer periods, selecting those events large enough to generate waves in that period band. Clearly no such model can be unique, but just as clearly at least one such model must exist. Later we'll strive for higher resolution using shorter periods.

Why does earthquake shaking vary so strongly from place to place, even across the street? We still lack a detailed answer to this simple question, even though we know that source, propagation, and site effects are all important. We'll have important new data from well logs and borehole seismometers in the Los Angeles basin, and we'll give high priority to analyzing these data and to designing new experiments to measure the wave field at the surface using array techniques.

Our most important challenge is to define our mission beyond 2002, the final year of our authorized funding as a National Science Foundation Science and Technology Center. NSF will entertain new proposals for Centers in 1998, and we are eligible to apply. However, award criteria will emphasize new research, not more of the same. Our Steering Committee and Advisory Council met for two days to consider our response. We agreed unanimously that we want to reapply, that we must make use of the scientific infrastructure we have built in southern California, and that we should try to preserve the basic organizational structure that has worked so well for us. We agreed that we should focus more than ever on the physical master model relating earthquake hazard to stress accumulation, developing its prediction capabilities to the fullest extent possible. This means we need to measure the fault geometry, surface deformation field, and mechanical properties as accurately as possible. We can never determine the initial conditions of stress before the seismic record began, but we can eliminate some configurations that violate the earthquake history. We also agreed that we need something new. Proposed new ingredients included a major international earthquake forecasting effort; an all-California Center, or even a western states center; and full collaboration with structural engineers to model earthquake waves in structures. We'll discuss these options at the annual meeting, and soon name a committee to begin work on a new proposal.

We can take pride in our accomplishments, but we have enormous challenges ahead. Many eyes will watch our response. 1998 will surely be a pivotal year for the Southern California Earthquake Center.

SCEC Knowledge Transfer

**Report to the Advisory Council
by Jill Andrews**

October 1997

Looking Back and Marching Forward

SCEC's Contributions to Knowledge Transfer

by Jill Andrews

(excerpt from SCEC Newsletter Vol. 3 No. 2)

The Knowledge Transfer Program's staff (Mark Benthien, outreach specialist, and Ed Hensley, writer/editor, and I) tackle the task of converting scientific results into more broadly understandable form. We make research socially relevant. We turn information into products.

But that makes it sound more one-way than it really is. Stephen Gould, scientist and social commentator, once said,

It is not possible to act like an objective fact-gathering robot, and if we think we can, we're just deluding ourselves, and we're going to be more subject to the prejudices we don't even know we have because we're not scrutinizing them.

He was talking about the relationship between science and society. His overall point was that when things are working at their best, the exchange of insight, realization, and understanding flows freely both directions. In fact, in all directions. That, in a nutshell, is what the Knowledge Transfer Program is here for: to open channels and keep ideas flowing.

As Knowledge Transfer Director for the Earthquake Center, I'm often responsible for describing the research conducted by Center scientists and explaining its relevance and applicability. At times, just keeping up with what SCEC's own researchers are doing feels as though we're trying to move a mountain with teaspoons. Since each investigator submits an annual summary of studies in progress, I have access to a great deal of information. That's one of our "mountains." The sheer volume of archived data, technical reports, and research papers in itself requires constant management to keep it organized so that it's available and accessible when needed for any purpose—technical or nontechnical. As for our "spoons": you're reading one, and you're about to hear about others.

SCEC now enters the second half of its eleven-year life span as a National Science Foundation Science and Technology Center. That means that we've had a half-life of experience to learn from. It also means that it's time to take stock and plan for the remainder. I want to do that here for the Knowledge Transfer portion of SCEC: give you a little history, share some accomplishments and some plans for the next half.

The SCEC Knowledge Transfer mission is to heighten public awareness and reduce earthquake losses by transferring research results and products to the community at large. To fulfill this mission, we aim to create a transportable program that organizes the ever-growing knowledge bases of academic scientists, engineers, and social scientists and makes sure that their work is applied to reducing earthquake-related risks. We

essentially have two target audiences for our products: the community of scientists and technical professionals working in related fields and the general public. In both cases, we aim specifically at our region first, but eventually at the entire world of scientists and the national public.

In preparing for the future, our plan is to identify Knowledge Transfer's most successful and productive outreach efforts and then to make sure we concentrate on what works and make it better. We plan to base all our efforts on the strong foundation we've established, especially our extensive, growing network of partners, contributors, and collaborators. We work in a multi-disciplinary, multi-institutional research environment, and we have gained expertise at translating scientific data and information into products and services for technical users and the general public.

How did we begin?

Early in the program's history, we convened a group of experts who aided us in identifying appropriate end-users for the Center—our clients. They also helped us establish objectives:

- Initiate and maintain personal contact with research scientists, engineers, social scientists, and end users through meetings, workshops, seminars, and field trips.
- Form mutually beneficial partnerships and alliances.
- Network: exchange ideas and information with other organizations.
- Disseminate products using multimedia tools and techniques.
- Promote sustainability through development of funding sources.

SCEC's Knowledge Transfer Program has proven to be an effective broker of information between the academic community and practitioners, between earth scientists and engineers, and between technical professionals and public officials. As a result, the Center is becoming known for its effective partnerships with local, state, and national government entities, academic institutions, industry, and the media.

What have we accomplished?

Before the Knowledge Transfer Program was formally established, Center scientists launched a seminar series in 1992. Building on that model and using the research results presented in the science seminars, the knowledge transfer staff designed workshops for targeted end-users. Since then the Knowledge Transfer Program has been involved in organizing workshops or symposia covering a variety of earth science and engineering topics and benefiting science faculty, post-doctorals, graduate students, and undergraduate students from member institutions and affiliated institutions.

Following the 1994 Northridge earthquake, we cosponsored a public workshop entitled "One Year after Northridge," in partnership with the Governor's Office of Emergency Services. Present were about 300 scientists, engineers, public officials, disaster preparedness and response officials. The workshop was an important focal point for both organizing the research and lessons concerning that earthquake, but also sharing information and implications concerning understanding and preparing for other earthquakes.

We chose this venue to release the seminal *Phase II Report—Seismic Hazards in Southern California: Probable Earthquakes, 1994-2024* and to conduct a press conference with the principal authors, who explained the significance of the report. The Phase II report generated concern among city and county engineers, building officials, and planners, so we started a series of vulnerability and seismic zonation feasibility workshops. We presented information on the vulnerability of various building types, bridges, and lifelines to over 200 attendees at two major workshops in 1995 and 1996.

Those workshops led directly to a dialogue among structural engineers, civil engineers, geotechnical engineers, building officials, planners, and earth scientists that became the Ground Motion Joint Task Force, a 48-member task force jointly sponsored by the Structural Engineers Association of Southern California (SEAOSC), the California Division of Mines and Geology (CDMG), and SCEC. The task force is studying the types of vulnerable structures common to Los Angeles.

FEMA is funding the production of two booklets to be published in the coming year to make the public aware of the hazards posed by those structures during earthquakes. The task force has already tackled structures such as the ubiquitous tuck-under parking buildings (a well-known example is Northridge Meadows Apartments) and nonductile concrete buildings (e.g., concrete parking structures and some older office buildings). The task force plans to encourage city council members to take action to protect occupants of these types of structures.

We also cosponsored with CDMG the “Zones of Deformation” workshop. Participants represented a cross-section of the geological, engineering, and planning communities. The focus was to provide advice to CDMG about establishing guidelines for the delineation, evaluation, and mitigation of zones of deformation. Three issues were discussed: zoning—identifying and defining the hazard; site-specific hazard investigation; and mitigation.

The California Universities for Research in Earthquake Engineering (CUREe) recently submitted a proposal entitled “Earthquake Hazard Mitigation of Woodframe Construction” to FEMA’s Hazard Mitigation Grant Program (Northridge Earthquake). The three-year project will include these components: testing and analysis, field investigations, building codes and standards, economic aspects, and education and outreach. As associate project manager for education and outreach, I will work with CUREe to develop education and training for home owners, apartment building owners, officials, and others

We also addressed requests from the insurance industry by forming a steering committee that designed insurance vulnerability workshops, focusing on evaluation and upgrading of current methods used by the insurance industry in measuring exposure. The first two workshops, held in 1995 and 1996, were attended by over 400 representatives from the insurance and reinsurance industries, as well as earth scientists and earthquake engineers. The workshops promote two-way communication and increased understanding of the earthquake threat in southern California. As a next step, we plan a series of small workshops to continue the dialogue and produce documentation. They will be focused on specific areas of concern to both primary insurers and reinsurers.

New and Innovative Technologies

As with any other effort that involves a high degree of coordination and time-sensitivity, the emergency management community must incorporate new and emerging technologies just to keep itself functioning as it should. It must be aggressive in that effort if it hopes to make progress in preparing to meet its ever-more-complex responsibilities. New technologies can gather better and faster information, can disseminate better and faster information, and can help coordinate those two more efficiently. We have been involved with our partners in both the public and private sectors to design workshops that promote sharing information between the producers and the users of those technologies. Emergency managers can find out what's out there to make their work more effective, and technology providers can find out what is needed and, therefore, what they will have a better chance of selling.

We conducted three workshops on geographical information system (GIS) use for scientists, engineers, and government representatives. Topics included comparisons of hardware and software, and data disclaimers. We also cosponsored "Making the Most of New Real-Time Information Technologies in Managing Earthquake Emergencies," a workshop jointly hosted by SCEC, USGS, CDMG, California Emergency Services Association (SCESA), OES, and Caltech. Attendees included 125 emergency management and response personnel and represented business resumption and contingency planners, business and finance communities, public information officers, and local governments.

The Internet

The SCEC site on the World Wide Web represents the ongoing research and results from all seven core institutions. It provides links to related web sites, including nine SCEC-supported standard databases. You can learn about our featured products, educational products, and project data. You can link to the 50 institution members of the Earthquake Information Providers (EqIP) group and to many other interesting educational sites. The SCEC site receives about 1,000 hits per month; the SCEC Data Center receives about 100,000 hits per month. If you have access to the Web, visit us at WWW.SCEC.ORG.

Community Education

Our outreach to the general public includes hosting a series of town meetings sponsored by state senators. SCEC provides speakers and materials that address the earthquake hazard, risk assessment, and mitigation steps. Each meeting is tailored with information on protecting the homes and the neighborhood infrastructure of a sponsoring senator's district.

SCEC is also pilot testing a model program that provides information and guidance to entire urban neighborhoods to help residents and homeowners become uniformly prepared to protect the lives and property. The year-long pilot is being conducted by SCEC's education and knowledge transfer staff in cooperation with the USC Department of Psychology, which will be assessing pre- and post-program attitudes in addition to the preparedness level of residents. The pilot is being conducted in a low-income, ethnically and culturally diverse neighborhood near South Central Los Angeles.

We believe in the importance of hands-on knowledge transfer. As part of our informal education effort, we conduct local field excursions, highlighting seismic hazards for practicing professionals (geotechnical, structural, and civil engineers); city, county, and state officials; other scientists; high school and community college instructors; utilities, transportation, and telecommunications industry representatives; and public and private emergency preparedness and response professionals. Accompanying field guides are published by SCEC's Knowledge Transfer Program for public distribution.

Southern California museums are also targeted by SCEC, which has developed a series of prototype mechanical exhibits that inform the public about natural hazards and earthquake engineering concepts and practices.

State mitigation plan

Our involvement in the earthquake safety community and the effects of our work go beyond our southern California borders. Representing SCEC and the knowledge transfer community in general, I served during 1996-1997 as a member of the writing team in the area of education and information dissemination for the state's earthquake hazard mitigation plan. A Seismic Safety Commission publication, *The California Earthquake Loss Reduction Plan*, should be off the presses this fall. Besides being required by FEMA before the release of any mitigation money, FEMA plans to use this plan as a model for other states. Among the initiatives we wrote are ones for legislation to set licensing and competency requirements for practicing professionals; short courses and other means to increase the level of understanding among the media and the public; workshops for state, city, and county officials on vulnerability assessment and loss reduction measures; and the establishment of a statewide K-12 earthquake education program.

Our work with the Seismic Safety Commission, the California Division of Mines and Geology, and the City of Los Angeles has helped strengthen the resolve of public officials to improve mitigation strategies. Earthquake scenarios now under development (for the Phase III report) will provide much more realistic estimates of expected ground shaking in the metropolitan areas of southern California. The probabilistic hazard assessment methods and earthquake scenarios being developed for southern California can be transferred nationwide. Already they are beginning to be emulated in northern California and in the Pacific Northwest.

Key Publications

Finally, a couple of other publications deserve mention. Our most successful endeavor to date has been a public awareness booklet. In 1994-95, we developed and produced two million copies of *Putting Down Roots in Earthquake Country*, a 32-page, full-color nontechnical version of the *Phase II* report. The booklet was directed to a diverse audience of disaster preparedness and response personnel, city and county officials, engineers and planners, the general public, and the media. Two-thirds of the publication run was distributed through all 12 of southern California's county public library systems; the remaining stock has been distributed through the SCEC office. We are now negotiating a reprint of the booklet, adding a Spanish language version, in partnership with a local television station.

And if you're a reader of our *SCEC Quarterly Newsletter*: We feature ongoing research and activities sponsored by the Center, and include in each issue a list of the latest Center publications. We publish scientific and technical articles written by SCEC scientists, researchers, and staff and glean interesting information and articles from other organizations emphasizing research on earthquake phenomena. Readers include representatives of the U.S. government; California state, county, and city government agencies; business and industry leaders interested in earthquake hazard mitigation; academic institutions, including pre-college teachers and students; the media; and the general public.

Where do we go from here?

We've identified a series of tasks that will aid us in meeting our longterm objectives, and we've attached to the tasks our plans for the next five years (see Appendices A & B and "Highlights of Knowledge Transfer Projects"). The tasks tell a story: where we've been, where we are, and where we're going:

- Investigate SCEC source strengths and capabilities in the context of user needs.
- Identify user groups appropriate to earthquake-related information, knowledge and technology.
- Initiate and maintain a mutually influencing network among user group representatives.
- Interact with end user representatives to identify potential products, linkages and opportunities.
- Implement a dynamic research utilization plan that involves researchers and end users in developing and participating in technical seminars, workshops, short courses, field studies, published products, and partnerships.
- Iterate the utilization plan to refine products, strengthen linkages, and expand opportunities.

Among the most important activities for the coming year are our media-related activities that promote awareness and loss reduction, such as the "L.A. Underground" radio spot series (and accompanying book) with KFWB Radio Anchor Jack Popejoy. As part of the second printing of *Putting Down Roots*, KTLA Television will be launching its own television spots or vignettes that encourage earthquake preparedness.

Partnerships with the media will be fundamental to getting out our message. One of our baseline efforts will be a guide for the media themselves, providing them with basic information, contacts, and guidelines related to earthquake preparation and response. In the coming months, we will plan a workshop to produce a media information guidebook, special Web site, and field training.

Our readers should look for the *Phase III* version for practicing professionals, authored by Edward Field, a SCEC research scientist at USC. We also plan to feature the newest research on ground motion scenarios in future versions of *Putting Down Roots*. Of course, Web surfers will see us continue to promote product usage and data dissemination via the SCEC Web pages and links, the SCEC infrastructure facilities, and the online databases. And we're continuing to expand our outreach to both national and international communities.

Appendix A: Mission, Goal, Objectives, Tasks

Mission

To heighten public awareness and reduce earthquake losses by transferring SCEC research results and products to the community at large.

Goal

To apply the combined, dynamic knowledge bases of scientists, engineers, and social scientists to earthquake loss reduction by implementing a transportable knowledge transfer model.

Objectives

- Initiate and maintain personal contact with research scientists, engineers, social scientists, and end users through meetings, workshops, seminars, and field trips.
- Form mutually beneficial partnerships and alliances.
- Network: exchange ideas and information with other organizations.
- Disseminate products using multimedia tools and techniques.
- Promote sustainability through development of funding sources.

Knowledge Transfer Model (How we do what we do):

- Investigate SCEC source strengths and capabilities in the context of user needs.
- Identify user groups appropriate to earthquake-related information, knowledge and technology
- Initiate and maintain a mutually influencing network among user group representatives.
- Interact with end user representatives to identify potential products, linkages and opportunities.
- Implement a dynamic research utilization plan that involves researchers and end users in developing and participating in technical seminars, workshops, short courses, field studies, published products, and partnerships.
- Iterate the utilization plan to refine products, strengthen linkages, and expand opportunities.

Appendix B: Funding Sources, Partnerships and Alliances

Government Agencies - Federal

- NSF** Principal funding agency: STC industry liaison annual meetings; participation in selected program development, such as the urban infrastructure initiative; and E&O directors meetings
- USGS** Co-funder with NSF; "Putting Down Roots in Earthquake Country;" joint science seminars, technical and non-technical workshops; IASPEI workshop on international outreach activities, 1997)
- FEMA** Technical Clearinghouse participation; "spot bill" proposal for post-earthquake funding for SCEC research and outreach activities (Region IX); funding for "Putting Down Roots," Media workshop,
- CLA/SEAOSC/SCEC** Public-Private Partnership public awareness booklets on two vulnerable structure types in L.A.
- CUREe Woodframe Project** 3-year Project to do Outreach; numerous other projects.
- LANL** (Los Alamos National Laboratory, New Mexico.) Joint project to convene a workshop in 1998 on "Earthquakes and urban Infrastructure."

Government Agencies - State and Local

- CDMG** Joint Task Force, CLA/SEAOSC/SCEC vulnerability study; joint sponsorship of Zones of Deformation workshop series; MOU to "wholesale" data and information to CDMG for public policy interpretation
- CA-OES** Technical Clearinghouse group leader, Archiving and Distribution of Data; "spot bill" in process, SEAOSC/CLA/SCEC - JTF; Joint partnership to produce a post-earthquake Media Guide, 1997.
- SSC** Group leader, rewriting the Education and Information Dissemination Chapter of California's Earthquake Loss Reduction Plan
- Los Angeles** (City and County of): Joint Task Force, SEAOSC/City of LA/SCEC, to study ground motion and site effects in specific zones in the L.A. region, and make recommendations on vulnerable building types
- State Senator Betty Karnette:** Town meetings to promote awareness in Palos Verdes

Other Organizations

- AEG** "Earthquake Hazards and Mitigation in California" workshop for legislative aides; joint workshops on fault and fold databases)
- ASCE** Presentation, commissioned paper "Earthquake Reconnaissance and the Internet," and attendance, annual meeting)
- AGU** Attend annual meetings

- EERI** Presentation, commissioned paper, "Earthquake Basics" series, and attendance, annual meetings; participation in post-earthquake technical clearinghouse; participation on committee for coordination of earthquake information organizations.
- IIPLR** Annual Congress, "Earthquakes and Insurance," 1997.
- IRIS** Incorporated Research Institutions in Seismology annual meetings
- NISEE/EERC and NISEE/Caltech** EQNET/EqIP; MOU with library systems.
- NCEER** Nat'l Center for Earthquake Engineering Research, Buffalo, NY: EQNET/EqIP steering committee and Web Page.
- SSA** Annual meetings - exhibit booth and posters
- WSSPC** Presentations and attendance, annual meetings
- CUREe** FEMA Woodframe proposal, outreach component; NSF PEER proposal, outreach component; presentation, commissioned paper, "SCEC Information Dissemination," Northridge conference, 1997.
- SEAOSC** Joint Task Force, Seismic Zonation, City and County of Los Angeles; two public awareness booklets on Non-Ductile Concrete and Tuck-Under Parking Buildings (funded by FEMA).
- NHRAIC** Presentations, attendance, annual workshops.

Emergency Preparedness and Response Organizations

ACP, BICEPP, SCESA, Mitigation and Response Technologies and Alliances (MRTA), and OCDRA – (membership and attendance at regular meetings of local and regional industry and business communities concerned with emergency preparedness and response)

Multi-organization sponsored event ("Making the Most of New Real-Time Information Technologies in Managing Earthquake Emergencies," jointly hosted by SCEC, USGS, CDMG, California Emergency Services Association (SCESA), the Governor's Office of Emergency Services, and CIT)

The Media

KFWB Radio weekly spots and WWW earthquake site on SCEC

KTLA-TV re-release of 5 million copies annually of "Putting Down Roots in Earthquake Country"

KTLA-TV earthquake awareness television vignettes

KTLA-TV weekly "chat room" on the Internet

KTLA-TV publication of Spanish language version of "Roots"

Media workshop series plans and field trips

Proposals for additional funding:

- \$23,000 Proposal to the USC Community Involvement project, joint with Education outreach director, 1997, FUNDED
- \$25,000 Proposal to FEMA for two public awareness booklets on vulnerable structures in the LA area, August, 1997, FUNDED
- \$100,000 proposal to KTLA-TV for existing stock and to consult in production of 5 million copies of an updated version of "Putting Down Roots," in English and Spanish, by Spring, 1998: IN PROGRESS
- Partners in a \$6.8 million proposal to FEMA, Earthquake Hazard Mitigation of Woodframe Construction: education and outreach project director, with an \$859,712 budget.
- Associates program with Education director (progress halted 1996; re-evaluated and green lighted for 1998)

Highlights of Knowledge Transfer Projects

Partner	Project Description
Publications	
<i>Putting Down Roots in Earthquake Country</i>	A 32-page, full-color nontechnical overview of earthquake probabilities, risks, and preparation
<i>SCEC Quarterly Newsletter</i>	Ongoing Center research and activities, lists of Center, scientific and technical articles by SCEC scientists, researchers, and staff, and interesting information from related organizations
Phase I Report :	<i>Future Seismic Hazards in Southern California, Phase I: Implications of the 1992 Landers Earthquake Sequence</i> : First stage of a comprehensive assessment of the earthquake risk in southern California; discusses the recent increase in the frequency of earthquakes in southern California, makes several recommendations for further study
Phase II Report:	<i>Seismic Hazards in Southern California: Probable Earthquakes, 1994-2024</i> Second stage of our overall assessment of the earthquake risk, giving the probability of earthquake shaking strong enough to cause moderate damage, specifically predicting 80- 90% probability of an earthquake M 7+ before 2024.
Phase III Report: [in preparation]	Builds on Phase II; includes source effect, site conditions, propagation path effect on strong ground motion. Two-part report will contain sample probabilistic seismic hazard maps and consensus time histories for selected earthquake scenarios and sites in southern California.
KFWB Radio Anchor Jack Popejoy "L.A. Underground" radio spots	One of several media-related activities to promote awareness and loss reduction
www.scec.org	World Wide Web site containing access to organizational information, data, and links to related topics and organizations
Workshops	
USGS, CDMG, SCESA, OES, Caltech	"Making the Most of New Real-Time Information Technologies in Managing Earthquake Emergencies"
OES: One Year after Northridge	300 scientists, engineers, public officials, disaster preparedness and response officials shared experiences, research, and insights
IASPEI	Educating the Public about Earthquake Hazards and Risks A one-day workshop we led at the general assembly of IASPEI in Greece; future workshops planned (IUGG 1999).
Insurance industry	Insurance vulnerability workshops evaluation and upgrading of current methods used by the insurance industry in measuring exposure.
CDMG	Zones of Deformation workshop to provide advice to CDMG about establishing guidelines for the delineation, evaluation, and mitigation of zones of deformation

Partner

Project Description

Ongoing or Planned Projects

CUREe/PEER	A new alliance to support the outreach efforts of the proposed Pacific Earthquake Engineering Research center.
CUREe	Earthquake Hazard Mitigation of Woodframe Construction, 3-year project covering all aspects of woodframe construction, including education and training
SEAOSC, City of L.A.	Ground Motion Joint Task Force to study vulnerable structures in southern CA
EERI & OES	Post-Earthquake Technical Clearinghouse: Hardware and Archiving and Distribution working groups
ACP, BICEPP	Annual Conference Presentations to keep the emergency planning and response communities informed
NCEER, SSC, NISEE /EERC (UC Berkeley) & NISEE/Caltech	Earthquake Information Providers Network; NISEE/Caltech Library loan agreement for exchange of materials and library assistance to end users.
KFWB Radio Anchor Jack Popejoy	"L.A. Underground" : The Book. Now under construction: a collection of the best and most compelling spots, with graphics, photos, illustrations. To be mounted on the WWW and produced in hard copy. Look for it in the Spring of 1998!
SSC	<i>The California Earthquake Loss Reduction Plan</i> : participation on the writing team in the area of education and information dissemination for the state's earthquake hazard mitigation plan
KTLA TV	Second printing of <i>Putting Down Roots</i> . Television spots and vignettes that encourage earthquake preparedness & newest research on ground motion scenarios
OES; USGS; all media	Media information guidebook to provide media with basic information, contacts, and guidelines related to earthquake preparation and response
Edward Field	Phase III report, "nontechnical" version: A version for practicing professionals who may use portions of the report to aid in the design of new structures in seismically active areas.
FEMA; Ground Motion Joint Task Force	Two booklets to increase public awareness of the hazards of vulnerable structure types (nonductile and tuck-under parking) in L.A. area.
WSSPC	1998 Conference sponsor on Hazard Insurance Policy to help formulate and act on a national all-hazard approach to address this critical issue.
The Reitherman Co.; San Jose State Univ; City of San Jose; CA Office of Trade & Investment; US Embassy, Japan	Fourth Int'l Conference on Corporate Earthquake Programs, Nov. 11-13, 1998. Objective is to improve status of corporate eq. preparedness programs by bringing together risk managers, eq. hazard reduction practitioners and researchers from both private and public sectors. Focus is on development of hazard reduction technologies; education and training; emergency preparedness and planning; and private sector and community earthquake safety.

IASPEI = International Association of Seismology and Physics of the Earth's Interior; ACP = Association of Contingency Planners; BICEPP = Business and Industry Council on Earthquake Preparedness and Planning; WSSPC = Western States Seismic Policy Council

Southern California Earthquake Center

Highlights of SCEC's Global Science Classroom 1997

I. Introduction

SCEC continues to make gains in the educational program it set out to develop and manage as a result of strategic planning in 1996. Significant are the formation and maintenance of two more school district partnerships, the continuation and refinement of academic-year and summer research opportunities for undergraduate and high school students, continuation of enrollment of schools, community colleges and universities in the CUBE project and progress in creation of unique and innovative SCEC educational materials.

New for 1997 was the development and testing of more comprehensive community education models as alternatives to earthquake preparedness and other short-term "special" events. SCEC staff had determined that special events were less appropriate to the SCEC education mission and not very productive education or mitigation strategies. The anticipated announcement of one or more new earthquake engineering research centers by the National Science Foundation prompted planning of joint programs with the proposed Pacific Earthquake Engineering Research Center.

Against these accomplishments was the void left when FEMA announced that it was not renewing any of its education program contracts, of which SCEC was one of several in the nation. This unanticipated change caused a cutback in education staff participation from 100% to 60%. Nevertheless, staff continued to fulfill the terms of the present FEMA contract and maintained -- even continued to develop new projects to which it had committed in the overall 1997 Workplan.

II. School District Partnerships

Development and management of long term (five-year) partnerships with selected school districts have been SCEC's response to K-12 school needs, especially for those which do not qualify under NSF's Urban Systemic Initiatives (USI). The philosophy and work is, however, similar to that undertaken by USI districts throughout the country, namely fundamental systemic restructuring of K-12 science programs. For each district, this entails planning, identifying and pursuing opportunities, professional staff development (teacher training), student services, equipment and supplies, financial development and community interfacing. SCEC's participation with the districts is uniquely fashioned to meet the needs of each. SCEC envisions itself as neither leader (the school district's role) or follower, but strategic supporter. In that role, it has been highly successful. SCEC is also the benefactor of teacher and student populations that are committed to help test and carry out experimental ideas for the Center's future development or full scale implementation.

All the partner Districts have either Blue Ribbon Schools or California Distinguished Schools status, thereby making the prospect of teacher and student success more promising for SCEC. Combined, SCEC's science education partnerships serve a K-12 student population of over 30,000.

A. Palos Verdes Peninsula Unified School District

SCEC is approaching the third year of the most mature of its five-year partnerships. This year marked the development of a high school field geology course, which SCEC inspired and is supporting. In 1997, the PV District also undertook a full-scale restructuring of the intermediate school program, of which science is a centerpiece.

SCEC assisted with the development of a proposal to NSF's Projects for Women and Girls to support the implementation of the program. Actually, the proposal was a resubmission of a previous proposal which was not funded; the district, however has not succeeded in the second attempt. SCEC ensured that a proposal to carry out a high school teacher-student research team project included PV, and a proposal to local industry, Allied Signal, has just been submitted to create a three-year restructuring project that has as its main features a comprehensive secondary teacher enhancement plan, student research opportunities and an area science academy for advanced science education. SCEC continues to help implement a natural habitat investigation program for all grades, K-5 in all elementary schools District-wide.

Of exceptional noteworthiness, SCEC's support of a high school student's math research project led Eleanor Williams to tie for sweepstakes (first place for all divisions and categories) in the Los Angeles County Science Fair and First Place in the Senior Math Division at the State Science Fair.

An attached letter to PVPUSD Superintendent, Ann Chlebicki, provides more detail on accomplishments of this partnership.

B. La Canada Unified School District

Early this year, discussions about a possible partnership with the La Canada Unified School District led to start-up activities. The advantages of working with La Canada are:

- its geographic location across the Los Angeles Basin from Palos Verdes, making the sharing and comparison of student data from classrooms in both locations an exciting prospect. This was viewed as particularly useful in the SCEC Science Module on GPS (to be discussed);
- the performance levels of students, which is high and similar to those in PV;
- commitment of SCEC scientists to participate in this partnership;
- proximity to the Jet Propulsion Laboratory, which already has a partnership with the District; and
- the District's size, smaller than PV, thereby making it manageable for SCEC staff.

The services for the first year of this partnership are attached.

C. Rialto Unified School District

The Rialto Unified School District is the largest of the three partners, with two high schools and five middle schools. The Rialto District serves yet a different role by its geographic location in Riverside County and its much more ethnically and racially diverse student population with sizable numbers of African American and Hispanic students.

The partnership was inspired by the 1996 visit by Dan Golden, NASA Administrator, who, at Rialto High School, announced the SCIGN. SCEC played a significant role in the arrangements for this visit and saw an opportunity to capitalize on the results of it. Rialto is also within the district of Congressman George Brown, whose office is continuously interacting with these schools. The draft five-year partnership workplan is attached.

III. Student Research Training

Students wishing to be competitive in college and career and to gain otherwise elusive scientific research experiences at their respective educational levels find opportunities in SCEC's student research programs. Research is often carried out with the guidance and supervision of SCEC scientists. SCEC's student research program criteria are updated

annually and are responsive to students in order to provide a diversity of research opportunities for them, especially within earthquake and earth science-related fields, although SCEC also supports student projects in the physical sciences, life sciences, math, engineering, education, relevant social science and computer science.

A. SCEC Summer Internships for Undergraduates

The SCEC Summer Intern Initiative was started in 1994 as a way to attract and retain undergraduates in the earth sciences, especially women and students from ethnic and racial backgrounds who are underrepresented in the earth sciences. This year, SCEC supported five undergraduate students. One Mexican female graduate student from CICESE in earthquake engineering also interned with Steve Day, a geophysicist at San Diego State University. Quite coincidentally and fortuitously, SCEC was actually supporting a student research project for which NSF was soliciting proposals. The program, entitled the "Integrative Graduate Education and Research Training Program (IGERT), promotes integrated, multi-disciplinary research such as the kind that SCEC supported this summer at San Diego State.

In addition, SCEC hosted its third of three FEMA-supported academic-year educational internships. This project is being carried out by an Hispanic-American female graduate student from USC, interning at the USGS-Pasadena.

All SCEC student research programs have been highly successful in promoting and realizing gender equity.

B. High School Research Traineeships

Four academic-year high school research projects were supported by SCEC in 1997. The projects were arranged by the Southern California Academy of Sciences Research Training Program (RTP), which has a distinguished record of success in student research, having cultivated several Westinghouse semifinalists and winners. All SCEC-supported projects this year were awarded to girls. SCEC has pledged support for 15 student research projects (five for each partner school district) for the 1997-98 academic year.

Tables showing the undergraduate and high school student researchers are attached.

IV. SCEC Science Modules (Educational/Program Materials Development)

The Earthquakes Center's research mission and work is being translated into educational experiences and materials for teachers and students. Although originally conceived as a way to highlight SCEC's Working Groups, the architecture for the program was refined this year into a more conceptually-based configuration. While this in no way interferes with the original intent of the project, it does streamline the effort and makes identification with the California Science Framework much more obvious. (Copy of revised plan attached.) These materials are inquiry-based, data-driven, Web-delivered and multi- and multiple media-rich, mirroring the state-of-the-art of educational technology and pedagogy.

A. GPS/SCIGN

This module was initiated as a SCEC Summer Intern project in 1996 and development has continued as funding and personnel have been available. It is the place in the development plan where the concepts of plate tectonics and crustal deformation are highlighted and where the data from the Southern California Integrated GPS Network is being packaged through classroom activities for use by secondary and college students. The URL for this work in progress: <http://jplmmw2.jpl.nasa.gov/maggiweb/index.html>.

B. Seismicity and Source Processes

Again, the SCEC Data Center is the main source of material for student investigations which probe the relationships between earthquakes and landform development, faults and earthquakes and patterns of earthquakes in southern California. The URL is: <http://www.scecdc.org/module.html>. It shows "What is an Earthquake?", "Foreshocks, Mainshocks, and Aftershocks" and "Geographic Distribution of Earthquakes."

C. CUBE

The first distribution of CUBE equipment to schools was completed in 1997, following a CUBE Educational Users Workshop in late 1996. At present, 11 schools, community colleges and universities are using the system as a result of participation in the workshop and subsequent registration as CUBE Educational Users. Another workshop is anticipated before the end of 1997.

V. Community Education Projects

Recognizing the need by Education and Outreach staff to develop and carry out more effective and durable models for programs for the general public, both E & O began pioneering new advanced strategies to interface with this vast user group. Replaced are the event-based activities such as appearances at earthquake fairs and festivals with programs that are community-specific, longer-term and multi-disciplinary.

A. Town Meetings with State Legislators

SCEC presently receives no direct E&O funding from the State of California. Yet it benefits from SCEC's scientific and E&O expertise. As a way to begin to cultivate such funding, SCEC began a series of Earthquake Town Meetings. With assistance from State Senator Betty Karnette's Long Beach office, SCEC conducted its first Town Meeting in April and participated in one of the Senator's community safety fairs on July 26. Another Town Meeting is scheduled for October. SCEC staff expects to offer more of these Town Meetings in other State Senate Districts in the future.

The purpose is two-fold: to provide community-specific earthquake hazard and risk information to citizens and constituents in legislative districts and to garner support for a statewide multi-sponsor earthquake E&O bill that may be introduced next session of the California Legislature.

B. ANNA-SCEC Neighborhood Earthquake Watch

A Mid-City, ethnically and economically diverse Los Angeles neighborhood association, the Adams-Normandie Neighborhood Association (ANNA), was awarded a \$23,750 USC Neighborhood Outreach Grant. This is the second grant for SCEC and a USC neighborhood partner. The previous grant was for the Summer VINE Project in 1995-96. Under this program, a not-for-profit community-based organization or school can form a partnership with a USC campus unit's faculty or staff to carry out year-long community or educational improvement projects. SCEC's E&O staff, together with faculty from the Department of Psychology are collaborating with the 250-household ANNA to carry out a neighborhood preparedness survey, structure a household and neighborhood education and mitigation program and provide for export of this model to other nearby neighborhood associations. The goal of the project is to assist the neighborhood in becoming uniformly prepared for a damaging urban earthquake. Features include Spanish translation of a new SCEC publication, *LA Underground* (based on the popular radio station KFVB public service series which features SCEC scientists), support (microcredit) for the creation of up to five small-scale enterprises for neighborhood residents for earthquake-related businesses, and participation in structural and nonstructural improvements to households by local home improvement stores and the

gas company (for purchase and installation of automatic gas shut-off valves through a grant-provided subsidies). Under terms of the Neighborhood Outreach Program, SCEC staff is not eligible for support, but students are. Therefore, this project has provided some support for one Ph.D. student from the Department of Earth Sciences and one Masters student from the Department of Psychology.

VI. Involvement of SCEC Scientists

The success of SCEC's Global Science Classroom would not be possible without the participation of SCEC scientists. And the key to success of their involvement is giving them educational tasks with which they are comfortable and in which they see their contribution being valuable to schools and the community. For example, most university-based student research internships are carried out under the supervision of SCEC scientists in the lab or field. All school district educational partnerships include SCEC scientists on their Advisory Committees. But they always do much more than advise. The most recent example is the participation of Lucy Jones, Ken Hudnut (USGS) and Monica Kohler (UCLA) who volunteered to work with the La Canada Unified School District. They took part in organizational meetings in the spring, participated in elementary and secondary teacher training workshops in the summer (Jones), and this fall, they will begin a Seismology Institute as part of the District's "Institutes for the 21st Century."

SCEC scientists in the Inland Empire will be called upon to assist with the Rialto District partnership, which SCEC is presently developing. It should be noted that SCEC scientists at JPL (Donnellan) and SCIGN (Bock) have been among those promoting and already lending support to this partnership.

The day-to-day development of SCEC Science Modules are overseen by scientists at the institutions and agencies at which they are being developed. The GPS/SCIGN Module is supervised by Donnellan at JPL, and the Seismicity and Source Processes Module is supervised by Egill Hauksson and Katrin Hafner at Caltech.

Community programs have had the benefit of participation by SCEC Scientists and other earthquake specialists as well. Town Meetings have involved Tom Henyey, Cheryl Tateishi and Mark Legg.

VI. Interface with the Pacific Earthquake Engineering Research Center (PEER)

Almost since the moment that PEER was proposed as a possible candidate as a new NSF Earthquake Engineering Research Center, its proposed Assistant Director for Education, Gerard Pardoen, UC Irvine, has consulted with SCEC staff on an E&O plan. The SCEC Summer Research Intern program was modeled in the PEER proposal and was further discussed in a meeting of SCEC education staff and PEER engineers hosted by SCEC on March 7.

Now that PEER is a reality, SCEC education staff expects a highly collaborative relationship, particularly in developing joint K-12 programs and a multi-disciplinary, integrated student research program at undergraduate and graduate levels. Besides the obvious educational benefits of working together, both organizations will be exploring the cost benefits of collaboration as well.

Submitted September 22, 1997 by

Curt Abdouch
Director for Education

ATTACHMENTS

SCEC SOUTHERN CALIFORNIA EARTHQUAKE CENTER



UNIVERSITY
OF SOUTHERN
CALIFORNIA

April 29, 1997

Dr. Ann Chlebicki
Superintendent
Palos Verdes Peninsula Unified School District
3801 Via La Selva
Palos Verdes Estates, CA 90274



CALIFORNIA
INSTITUTE OF
TECHNOLOGY

Dear Dr. Chlebicki:

RE: Palos Verdes School District/Southern California Earthquake Center
Educational Partnership



LAMONT-DOHERTY
EARTH OBSERVATORY
OF COLUMBIA
UNIVERSITY

Let me begin this letter with recent highlights that show real progress in our educational partnership. Last week, Eleanor Williams, a Junior at PV High not only won first place in the high school mathematics category, but tied for overall first place at the LA County Science Fair! Her long term academic-year math research project, which SCEC sponsored was guided by USC math professor, Slobadan Simic. Eleanor, together with Linda Tang from PV who conducted marine biology research project, also sponsored by SCEC in the same research program, will present their papers at the Annual Meeting of the Southern California Academy of Science this weekend. We were also impressed by the earthquake research posters that seniors in PV's unique Pacific Rim Studies Program prepared and exhibited at one of our state senator's earthquake "town meetings" which SCEC organized for local citizens. These accomplishments seem to provide ample evidence of the excellent effects that our educational partnership is having. Our investment of nearly \$30,000 in staff and Advisory Committee time and services, science equipment and supplies appears to be paying dividends.



UCLA

This letter is intended to communicate the continued partnership intentions of the Southern California Earthquake Center, University of Southern California with the Palos Verdes Peninsula Unified School District School District begun in 1996. Though little more than one year old, we have made significant strides, which we have summarized and attached to this letter. SCEC has recently established a comprehensive five-year educational partnership with the Palos Verdes Peninsula School District in suburban Los Angeles.



UC SAN DIEGO
SCRIPPS INSTITUTION
OF OCEANOGRAPHY

The education community throughout the nation believes that these kinds of comprehensive systemic partnerships are of great value in solving the country's science education crisis. The National Science Foundation is presently funding a number of initiatives in school districts -- both urban and rural -- across the nation in an effort to increase the effectiveness of science education for vast numbers of teachers and students.



UNIVERSITY OF
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SANTA BARBARA



UNITED STATES
GEOLOGICAL
SURVEY

Los Angeles, CA 90089-0742 • Telephone: (213) 740-5843 • Facsimile: (213) 740-0011
E-mail: sceinfo@usc.edu • Internet: <http://www.usc.edu/go/scec/>

As you know we are presently supporting the development of a high school field geology course that will be premiered next fall. We have assigned some of our geology faculty to assist and Dr. Robert Douglas, a new member of our partnership Advisory Committee, will be assisting helping science teacher, Jim Ryono, develop that course.

Dr. Jerry Mendel from USC has also joined our Advisory Committee. Together with the aforementioned new members, our Advisory Committee from SCEC has been active in helping to structure and monitor the partnership. Members are Tom Henyey, Earthquake Center Director; Hans Bozler, Chair of Physics and Astronomy, USC; Barney Pipkin, Professor Emeritus, Earth Sciences, USC; Bill Petak, Director, Safety and Systems Management, USC, Beth Petak-Aaron, William McComas, School of Education and Susan Yoder, USC Sea Grant.

SCEC is a multi-institutional and multi-disciplinary research organization. Seven institutions and agencies prominent in earthquake research -- USC, Caltech, the Universities of California Los Angeles, Santa Barbara and San Diego; and Columbia University and the USGS -- are SCEC's Core Institutions. Participating institutions and agencies include UC Riverside; University of Nevada, Reno; San Diego State; Harvard; Stanford; MIT; Princeton; Oregon State and the Jet Propulsion Laboratory. We will use the resources of several of our institutions to fulfill our commitment.

The partnership will address educational problems and issues over a five-year time horizon.

The following outlines some services that SCEC intends to provide and continue. Please note that it is not all-inclusive.

- To carry out staff development (inservice of) elementary and secondary classroom teachers;
- To provide SCEC scientists who serve as mentors and instructors for students and classroom teachers;
- To provide scientific equipment and supplies;
- To make or help make reports and presentations on the partnership to School Board members, PTAs and PV-based corporations and community groups; and
- To help furnish or develop financial resources to support the program.
- To provide incentives for students to enroll in SCEC institutions such as USC, Caltech, the Universities of California, etc.
- To link students with opportunities for engineering education and research through the Pacific Earthquake Engineering Research Center (PEER) should it be funded by the National Science Foundation

Services provided during the five-year partnership term emphasize the following:

- Teacher training with respect to the earth sciences, focusing mainly on geosciences and earthquakes;
- Utilization of the Palos Verdes peninsula environment as a natural laboratory for investigation;

- Enrichment of the science curricula at the elementary and secondary levels, with strong emphasis on (earth) scientific investigation processes -- i.e. data gathering, manipulation, analysis, interpretation and communication -- through traditional science and social science courses and a recently developed "research" course which is presently grounded in library/literature-based studies only. The enhanced class, with SCEC assistance will allow students to interface with SCEC scientists on projects;
- Mobilization of a large number of students who will be conducting various scientific studies over the five year time horizon of the partnership;
- Equipping the high school and middle schools with the technological tools -- GPS instruments, the CUBE seismic recording system, a gravimeter and a magnetometer -- and training staff and students to successfully use and maintain them;
- Linking the science education work in the schools with the community -- from local to global -- through telecommunications networks;
- Providing incentives for high achievement in science among high school students.

The Earthquake Center is looking forward to a long, productive and mutually beneficial relationship.

Sincerely,



Thomas L. Henyey
Center Director



SOUTHERN CALIFORNIA EARTHQUAKE CENTER



UNIVERSITY OF SOUTHERN CALIFORNIA

TO: C.T. HOLMAN and LA CANADA UNIFIED SCHOOL DISTRICT SCIENCE EDUCATORS



FROM: CURT ABDOUCH, DIRECTOR FOR EDUCATION, SCEC

RE: SCEC-LA CANADA EDUCATIONAL PARTNERSHIP ACTIVITIES

DATE: JUNE 4, 1997



LAMONT-DOHERTY EARTH OBSERVATORY OF COLUMBIA UNIVERSITY

SCEC Scientific Advisors for the SCEC-La Canada Educational Partnership are: Dr. Lucile Jones, Seismologist, United States Geological Survey (USGS), Dr. Ken Hudnut, Geologist, USGS and Dr. Monica Kohler, Seismologist, UCLA.

As a result of our last meeting on May 22, here are the activities, equipment and services SCEC is willing to provide or assist in accomplishing.



UCLA

- Curriculum enrichment:
 - Assistance with the restructuring of 8th grade earth/physical science curriculum
 - Assistance with the enrichment of the high school geology course



UC SAN DIEGO SCRIPPS INSTITUTION OF OCEANOGRAPHY

- Staff development:

Staff development workshop on *Tremor Troop* earthquake education materials for elementary schools (Sample of materials accompanies this memo.) Workshop to be scheduled for 2nd or 3rd week in July (3 days or less)

Staff development workshop on *Seismic Sleuths* earthquake education materials for secondary schools (Sample of materials accompanies this memo.) Workshop to be scheduled for summer, 1997 (3 days or less)



UNIVERSITY OF CALIFORNIA SANTA BARBARA

Facilitation and partial support/sponsorship of a math instructor to participate in a Discrete Math Institute at Rutgers University (summer, 1997)



UNITED STATES GEOLOGICAL SURVEY

SCEC has contacted the Governor's Office of Emergency Services (OES) which has agreed to conduct a staff training workshop on school safety and emergency preparedness (at least one full day at a time to be determined, summer, 1997).

- Institutes for the 21st Century:
 - Planning and conduct of a Seismology Institute
 - Assistance with the Rainforest Institute (field trips, fund raising)
- Student services:
 - Sponsorship of five (5) high school student interns to carry out academic year research with professional scientists
- Equipment:
 - Purchase of two (2) student-style seismometers
 - Purchase of one soil auger for Rainforest Institute
 - Loan of SCEC field investigation equipment for the geology course

Please note that Earthquake Center (with the U.S. Geological Survey --USGS-- and Caltech) already has provided a CUBE (Caltech-USGS Broadcast of Earthquakes) earthquake reporting system for the high school, has provided staff development and the CUBE Curriculum to staff.

La Canada also has been one of the school districts named as a partner in a teacher-student team science research project proposal submitted to the National Science Foundation on April 1.

c: Tom Henyey

DRAFT
Southern California Earthquake Center
and
Rialto Unified School District
Five year Plan for Educational Partnership

The following plan outlines proposed educational partnership activities between Southern California Earthquake Center (SCEC) and Rialto Unified School District, 1997-98 through 2001-02.

Year	For Teachers	For Students	Equipment/ Materials	Community	Other
97/98	<p>Assist in developing Student Internet Project (StIP). Elementary</p> <p>Assist in re-structuring of middle school science/health curriculum. Middle School</p> <p>Provide staff development for CUBE equipment installed at RHS. High School</p> <p>Provide San Andreas Study Trip for teachers on a Saturday.</p> <p>Provide staff development on Seismic Sleuths and Tremor Troop curriculum.</p>	<p>Assist in developing Student Internet Project (StIP). Elementary</p> <p>Support up to five secondary students for the training program of the Souther California Academy of Sciences.</p>	<p>CUBE equip-ment 96/97</p> <p>Install Global Positioning Station at 1 high school (GPS) as part of the 250 station Southern California integrated GPS network.</p> <p>Install seismometers at 2 high schools.</p>	<p>Assist in StIP Earthquake project.</p> <p>Assist in plans for possible community preparedness fair or other event.</p> <p>Investigate software to extend current lab probes available at M.S.</p>	<p>Support teachers at various levels to:</p> <ol style="list-style-type: none"> 1. Attend professional sciences meetings for secondary teachers. 2. Attend NSF Summer Institutes. 3. Arrange summer research projects with University scientists. 4. Assist with development of SCEC Science Education modules. 5. Assist as appropriate/necessary in grant applications at local, state and federal levels ie: GLOBE project

<p>98/99</p>	<p>Assist in revision/enrichment of 9th grade Physical Science Curriculum.</p> <p>Assist in preparation for K-8 science adoption 99/00.</p> <p>Provide workshops as needed for internet use in sciences/math.</p> <p>Provide Study Trip for teachers on a Saturday.</p> <p>Provide staff development on Seismic Sleuths and Tremor Troop curriculum.</p>	<p>Support up to five secondary students for the training program of the Southern California Academy of Sciences.</p>	<p>Use and maintain above equipment.</p> <p>Install seismometers at Milor and 2 middle schools.</p>	<p>Identify community-based science education resources through a task force.</p> <p>Investigate software to extend current lab probes available at M.S.</p> <p>Investigate establishing School Habitat program.</p>	<p>See above description.</p>
<p>99/00</p>	<p>Assist in Science Adoption process.</p> <p>Provide workshops as needed for internet use in sciences/math.</p> <p>Provide Study Trip for teachers on a Saturday.</p> <p>Provide staff development on Seismic Sleuths and Tremor Troop curriculum</p>	<p>Support up to five secondary students with Research Project applications and process.</p>	<p>Use and maintain above equipment.</p> <p>Install seismometers at 3 middle schools.</p>	<p>Continue to update local community-based science education resources.</p>	<p>See above description.</p>

<p>00/01</p>	<p>Assist in implementation of K-8 science adoption training.</p> <p>Provide workshops as needed for internet use in sciences/math.</p> <p>Provide Study Trip for teachers on a Saturday.</p> <p>Provide staff development on Seismic Sleuths and Tremor Troop curriculum</p>	<p>Support up to five secondary students with Research Project applications and process.</p>	<p>Use and maintain above equipment.</p>	<p>Maintain community-based science education resources.</p>	<p>See above description.</p>
<p>01/02</p>	<p>Continue to assist in science curriculum training.</p> <p>Provide workshops as needed for internet use in sciences/math.</p> <p>Provide Study Trip for teachers on a Saturday.</p> <p>Provide staff development on Seismic Sleuths and Tremor Troop curriculum</p>	<p>Support up to five secondary students with Research Project applications and process.</p>	<p>Use and maintain above equipment.</p>	<p>Maintain community-based science education resources.</p>	<p>See above description.</p>

SCEC Summer Interns, 1997

Name/Institution	Institution	Advisor/Inst.	
1. Carmen Alex	UC Santa Barbara	Kim B. Olsen UC Santa Barbara	calex@quake.crystal .ucsb.edu
2. Allan Tucker	USC	Bill Doll Oak Ridge National Lab	aztucker@earth.usc. edu d8e@oort.esd.ornl. gov
3. Ryan Smith	USC	David Okaya, USC	ryansmit@earth.usc. edu
4. Jana Juracy Soares Lopez	CICESE	Steve Day San Diego State	jsoares@cicese.mx
5. Neil Morgan	UC Santa Barbara	Ralph Archuleta UC Santa Barbara	morgan@magic.geol. .ucsb.edu
6. Erik Ronald	UC Santa Barbara	Ed Keller (Larry Gurrola, Molly Trecker)	ronald@magic.geol. ucsb.edu
7. Wendy Dailey	Cal Poly Pomona	C. Theodoropolis	wddailey@ csupomona.edu

**Support for the Southern California Academy of Sciences
for the
High School Research Training Program (RTP)
1997-97 Academic Year**

Student Name	High School	Research Advisor/ Institution	Research Project Type	Award
Eleanor Williams	Palos Verdes Peninsula	Slobadan Simic Math Dept. USC	Math	\$500
Linda Tang	Palos Verdes Peninsula	Southern California Marine Institute	Marine Biology	\$500
Rena Yee	Torrance	Steve Lund Earth Sciences. USC	Paleomagnetism	\$250
Sat. M. Ho	Abraham Lincoln, LA	C.B. Dea Occidental College	Biology	\$250

**SCEC Science Module Organization and Architecture
Version 1.0**

<p style="text-align: center;">Overarching/ Unifying Concept</p> <p style="text-align: center;">Module Title</p>	<p style="text-align: center;">California Science Framework Theme(s)</p>	<p style="text-align: center;">Major Topics</p>	<p style="text-align: center;">Content (concepts, ideas, questions)</p>
<p>1. Earthquake Hazard Assessment: A Systems Approach</p>	<p>Systems and Interactions</p> <p>Evolution</p>	<p>Master Modeling: Defining the Hazard</p> <p>Earthquake Engineering: Mitigating The Hazard</p> <p>Effects of Earthquakes: Spreading the Risk</p>	<p>Earthquakes are complex physical systems that must be studied by several means and must be understood from source to site.</p> <p>Earthquakes interact with the built environment; risk assessment and mitigation</p> <p>Earthquakes affect the natural and human environment and civil infrastructure: Structural and lifeline damage and disruption; effects of tsunamis; topographic changes (watersheds, mountains); landslides; human health -- physical and mental</p>

<p>2. Patterns of Earthquakes</p>	<p>Patterns of Change</p> <p>Scale and Structure</p>	<p>GPS/SCIGN; Crustal Deformation; Regionalizing the Pattern</p> <p>Seismicity</p> <p>Earthquake Geology; Localizing the pattern</p>	<p>Plate Tectonics, remote observation technology, stress and strain</p> <p>Earthquake pattern recognition (size and distribution); What valuable information do seismograms reveal? Time, fault systems, 3D space, focal mechanisms (see Seeber)</p> <p>Earthquake "anatomy" (faults); paleoseismology; fault slip rates and analysis of their effect on the crust past, present and future; error bars</p>
<p>3. Measuring Earthquake Waves and Ground Motion</p>	<p>Energy</p> <p>Stability</p> <p>Systems and Interactions</p>	<p>Ground motion: Wave effects at the surface</p> <p>Subsurface Imaging: Exploring the wave transmission medium</p>	<p>Wave amplitude; intensity; the seismometer and the kinds of measurements it makes; acceleration, velocity; displacement; seismic sea waves (tsunamis)</p> <p>Remote observation technology; focusing and defocusing (see Davis), LARSE</p>
<p>4. Physics of Earthquakes</p>	<p>Energy</p> <p>Systems and Interactions</p>	<p>Earthquake Physics</p> <p>Mechanics of Faulting</p>	<p>Earthquake "physiology"; rupture dynamics (How does a fault rupture?); magnitude; kinematics; directivity effects; preferred direction of wave energy, energy</p>

Asperity Model for the Nucleation of an Earthquake

M. S. Abinante and L. Knopoff
University of California, Los Angeles

We model the nucleation of an earthquake as the aggregate failure of an extended 1-D asperity having a spatially variable fracture threshold. Understanding the statistical micromechanics of such failure may lend insight to such macroscopic entities as rate- and state-weakening laws which play a very important role during the initial phase of an earthquake. In particular we investigate the temporal decay of strength of an asperity is under a homogeneous applied stress, and for this stress there exists a distribution of failure time, across the individual bonds of the asperity. As bonds fail, the redistributed stress diminishes the time to failure of the neighboring unbroken bonds. Thus our model is similar to a “fiber-bundle” model. Our model is substantially different from and more physically reasonable than hierarchical structures are imposed on the lattice, rather, microcracks within the asperity are allowed to grow quasistatically to an appropriate size determined by the fracture thresholds and the state of inhomogeneity of stress within the system; stresses are redistributed bilaterally over a distance scaled by the size of the microcrack. For a wide range of conditions, approach to total failure of the asperity is catastrophic. For a sufficiently extended period of nucleation it may be possible to predict the time of breakout of the earthquake. We show that it is not the total accumulated moment before a major earthquake that is a predictor, but rather it is the moment of the asperity still to be released that is a predictor of the time of breakout.

Lens-Effect in Santa Monica?

Carmen M. Alex and Kim B. Olsen
University of California, Santa Barbara

We have used finite-difference simulations of 10-Hz P-SV waves to analyze possible causes for the increased amplification observed for the 1994 Northridge earthquake and its aftershocks in the Santa Monica (SM) area, California. We use a series of models containing features suggested by Gao et al. (1996) to cause the amplification: the lower impedance of the LA basin sediments, the north-ward dipping SM fault, and/or a lens-shaped boundary between the sediments and bedrock below the SM Mountains. We simulate wave propagation for a 17-km deep M2.2 Northridge aftershock with epicenter 30 km north of SM. Relative to a bedrock site at similar epicentral distance we find peak velocities of up to 4 times larger within the area that was heavily damaged during the mainshock for a source with fault dip of 40 degrees. The focusing from the lens-shaped bedrock/basin boundary causes amplification factors of up to 2.5 in the heavily damaged area. Snapshots of the wave propagation identify the strongest phases arriving in the model of the SM area as laterally propagating converted waves amplified by the SM fault and in particular S waves focused by the lens-shaped boundary of the basin. These phases arrive 5-6 seconds after the direct P waves, similar to the relative timing of the strong secondary arrivals observed in Northridge aftershock data.

EDM and GPS Deformation Measurements on the Southernmost San Andreas Fault

Greg Anderson, Hadley Johnson, Duncan Agnew, and Frank K. Wyatt
University of California, San Diego

The southernmost segment of the San Andreas Fault has not ruptured in a great earthquake in more than 300 years; its interseismic deformation, particularly at its ends, is therefore of great interest. As part of a larger, NSF-funded, regional GPS survey this summer, we remeasured 10 of the USGS Geodolite lines along the eastern side of the Salton Sea from

Mecca to Calipatria. Preliminary analysis of these data together with the earlier Geodolite data shows unexpected temporal variations during the mid-1970s to mid-1980s which cannot be explained with simple linear models of fault slip, even after abrupt offsets are included to allow for the many earthquakes affecting the area since the early 1970s. Three years of data from two laser strainmeters at Durmid Hill do not display strain-rate changes of similar magnitude; however, these data do not overlap in time with the Geodolite data. We are left with the possibility that strain accumulation in this area from the mid-1970s to the mid-1980s was not steady, and are pursuing possible explanations for this.

Investigation of Historic and Paleoseismic Behavior of the South-Central San Andreas Fault between Cholame and the Carrizo Plain

J. R. Arrowsmith
Arizona State University
Lisa Grant
Chapman University
Dallas D. Rhodes
Whittier College

Paleoseismic investigations along the south-central San Andreas Fault (SAF) have provided data to test the hypothesis that faults may be divided into segments that are assumed to rupture with a characteristic (i.e., repeated in successive events) slip distribution. Recent paleoseismic investigations in the Carrizo Plain have promoted alternative interpretations that include events clustered in time and uncharacteristic slip patterns. The 1857 Fort Tejon earthquake was preceded by foreshocks at Parkfield, and the SAF apparently slipped there during the main event. Given that historic precedent, the several possible interpretations for the existing paleoseismic data, and the amount of loading along the south-central SAF since 1857; it is plausible that coseismic slip along the Parkfield segment of the SAF could propagate (or trigger an event) further southeast with a Mw of 7 or greater. We have begun to investigate this problem by analyzing offset landforms and historic survey data along the northern portion of the 1857 rupture. So far, we have found 9 survey marks in the field, thoroughly checked for two more, and recovered records of pre-1857 surveys and monuments. We have also mapped several km of fault trace geometry near Still Lake and Bitterwater Canyon, two sites that may be suitable for paleoseismic investigation.

Waveform Cross-correlation to Relocate the 1986 Oceanside, California Sequence

Luciana Astiz and Peter M. Shearer
University of California, San Diego

On July 7, 1986 a $M=5.3$ earthquake occurred about 50 km southwest and offshore of Oceanside, San Diego County, CA. Over 3,000 events clustered in an area of about 15 square km have occurred since in this region since 1980 and have been recorded by the Southern California Seismic Network (SCSN). Waveforms are available through the SCEC (Southern California Earthquake Center) Data Center. Locating these events accurately is difficult since they are situated well outside the network and relatively few travel-time picks exists for some of these events. First, we relocate all events from 1980 to 1996 occurring in the Oceanside event region using existing P and S picks by applying a L1-norm, grid-search algorithm that uses station terms to account for three-dimensional velocity structure outside the aftershock region. This procedure reduces the scatter in the epicentral locations, as compared to those in the catalog. Next, we perform waveform cross-correlation of event pairs to obtain precise differential times. However, analyzing every event pair becomes impractical for large numbers of earthquakes, so we apply cross-correlation only to nearby events. For each earthquake, we identify a target

number of surrounding events by computing the Delaunay tessellation of the relocated hypocenters and finding the natural neighbors of each event (Sambridge et al., 1995). The waveforms are low-pass filtered at 10 Hz and resampled to 100-Hz sample rate prior to the cross-correlation. For those event pairs sufficiently similar to provide well-defined peaks in their cross-correlation functions we obtain differential P and S travel-times. Next, we use the differential times, together with the existing travel time picks, to solve for an adjusted set of travel times that are more consistent and more complete than the original picks. The events are then relocated using the adjusted set of picks. Preliminary results show a complex structure consistent with the presence of the San Diego Trough-Bahia Soledad fault zone.

Sambridge, M., J. Braun and H. McQueen, (1995) Geophysical parameterization and interpolation of irregular data using natural neighbours, *GJI* 122, 837-857.

Geodetic Measurements of Horizontal Strain near the White Wolf Fault, Garlock, and San Andreas Faults, 1926-1997

Gerald W. Bawden and Louise H. Kellogg
University of California, Davis
Andrea Donnellan
Jet Propulsion Laboratory

We combined Global Positioning System (GPS) measurements with historical triangulation and trilateration data to determine changes in the strain rate for the Garlock-White Wolf-San Andreas fault system for seven decades (1926-97). We reanalyzed historical geodetic data and determined an elevated maximum shear strain rate of 0.62 ± 0.16 microstrain/yr across the White Wolf fault during the decades before the 1952 Kern County earthquake. The shear strain rate decreased towards the Garlock fault to barely detectable levels. In the decade following the earthquake (1952-63), the maximum shear strain near the fault was high (0.85 ± 0.23 microstrain/yr), and dropped to 0.23 ± 0.13 microstrain/yr across the Garlock fault. In 1993 we reoccupied the same network with GPS and found that the maximum shear strain rate across the White Wolf fault had dropped to less than a quarter of its earlier magnitude. In July 1997 we reoccupied both the White Wolf array and the SCEC Gorman network to determine a detailed velocity map for the Big Bend region of the San Andreas fault.

Properties Of Seismic Fault Zone Waves And Their Utility For Imaging Low Velocity Structures

Yehuda Ben-Zion
University of Southern California

A 2D analytical solution for a scalar wavefield in a structure consisting of two fault zone (FZ) layers between two quarter spaces, based on the results of Ben-Zion and Aki [BSSA, 1990], is used to study properties of seismic FZ waves. The interference patterns controlling the waves change with the number of internal FZ reflections. This number increases with propagation distance along the structure and decreases with FZ width. Thus the primary length scale governing FZ waves is the ratio of propagation distance along the structure divided by the FZ width. The critical angle of reflection increases with the impedance contrast between a low velocity gouge layer and the bounding media. Hence the number of internal FZ reflections increases (for given length scales) with the velocity contrast. The relative lateral position of the source within the FZ layer modifies the length scales associated with internal reflections and influences the resulting interference pattern. Low values of Q affect considerably the dominant period and overall duration of the waves. Thus there are significant trade-offs between propagation distance along the structure, FZ width, velocity contrast, source location within the

FZ, and Q. The calculations demonstrate that the wavefield depends strongly not only on receiver distance from the FZ, but also on receiver depth below the free surface. The strong parameter trade-offs imply that failure to account properly for some of the above effects is likely to produce errors and scatter in the other derived parameters. The results show that the zone connecting sources generating FZ waves and observation points with appreciable wave amplitude can be over an order of magnitude larger than the FZ width. Thus visual inspection of the region where seismic FZ waves exist may provide some general information, but it can not be used to conclude on structural properties and source offset from the FZ.

Patterns of Earthquakes and Faults in a Rheologically Layered Half-Space

Yehuda Ben-Zion

University of Southern California

Vladimir Lyakhovsky and Amotz Agnon

The Hebrew University, Jerusalem, Israel

We study the coupled evolution of earthquakes and faults in a model consisting of a seismogenic crust governed by damage rheology over a viscoelastic substrate. The damage rheology has two main functional coefficients: (1) a "generalized internal friction" separating states associated with material degradation and healing, and (2) damage rate parameters, one for positive changes (degradation) and two for negative evolution (healing). The parameters are constrained by acoustic emission and other rock-mechanics experiments [Lyakhovsky et al., JGR, '97]. The evolving damage modifies the elastic properties of material in the crust as a function of the ongoing deformation. This simulates the creation and healing of complex fault systems in the seismogenic crust. The equations of motion for the layered elastic/viscoelastic half-space are approximated by a modified version of the generalized Elsasser model. The generalized Elsasser model [Lehner et al., JGR, '81] simulates interseismic periods, whereas a new 3D elastic stress transfer scheme accounts for brittle failure episodes.

The above developments allow us to simulate the coupled evolution of earthquakes and faults in an internally consistent framework. The results indicate that low generalized internal friction and fast healing rate, describing a relatively weak upper crust with relatively short memory, lead to the development of highly localized, geometrically regular, fault systems. The associated seismicity patterns are compatible with the characteristic earthquake distribution and quasi-periodic temporal occurrence of large events. Conversely, high generalized internal friction and slow healing rate tend to lead to the development of a network of disordered fault systems. In such cases the corresponding frequency-size statistics of earthquakes are more power law like, and the temporal distributions of large events are random or clustered. The simulated seismicity patterns are non stationary in time and space, and the statistics depend on the sizes of the employed temporal and spatial domains. Model simulations with rheological parameters constrained by lab data exhibit alternating overall switching of response, from periods of intense seismic activity to periods during which the deformation occurs aseismically. The amount of time spent in each mode is on the order of 1000 yr.

Historical Earthquake Sequences in the Iranian Plateau

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The Zirkuh-e-Qa'enat earthquake of 10 May 1997 (M_s 7.3) on the NNW-striking Abiz right-lateral fault killed at least 1560 people, injured more than 4,400, and left 60,000 homeless. Up to 2.2m surface displacement was observed. The earthquake was preceded by two events in

1979 at the northern end of the Abiz fault: an earthquake of M_s 6.6 on 14 November with 20 km of surface faulting and another event of M_s 6.1 on 7 December, with surface rupture along the remaining 15 km of the Abiz fault up to its junction with the Dasht-e-Bayaz fault. The 1997 mainshock was just south of the 1979 earthquakes, and the earthquake propagated bilaterally to both ends of the Abiz fault, suggesting that the fault was loaded by the 1979 earthquakes.

The Dasht-e-Bayaz left-lateral fault includes a 70-km-long west segment that ruptured in an earthquake of M_s 7.4 on 31 August 1968. This started a sequence that propagated eastward with an earthquake of M_s 6.4 on 7 November 1976 near the segment boundary and an event of M_s 7.1 that ruptured the 50-km-long eastern segment of the Dasht-e-Bayaz fault on 27 November 1979. This last earthquake struck in the time period between the two Abiz fault earthquakes. A reverse-fault earthquake of M_s 6.8 struck near the eastern segment on 1 January 1979 (thereby initiating the short-term 1979 sequence), and a reverse-fault event of M_s 6.4 struck the Ferdows fault one day after the 1968 Dasht-e-Bayaz earthquake. Ten years later, on 16 September 1978, the Tabas reverse-fault earthquake of M_s 7.4 ruptured the Shotori range front 140 km to the southwest, across strike from Ferdows.

In the last nine centuries, only the Twentieth Century earthquakes show clustering in this region. Elsewhere, the North Tabriz fault system ruptured from east to west in three earthquakes in 65 years: the Shebli earthquake of M 7.3 on 26 April 1721 with surface rupture >35 km, the Tabriz earthquake of M 7.4 on 8 January 1780 with >42 km of surface rupture, and the Marand-Mishu earthquake of M 6.3 in October 1786. The Neyshabur-Binalud thrust belt was struck by four earthquakes in <200 years. The eastern segment was struck by earthquakes of M 7.3 in 1209 and 1389, and the western segment was struck by earthquakes of M 7.1 in 1270 and M 7.4 in 1405. This accounts for all moment release in this zone since the 7th Century, with the possible exception of a M 6.6 earthquake in 1673. These earthquakes may be cross-strike pairs like the Sylmar-Northridge pair in 1971 and 1994.

Interplay between strike-slip and reverse faults in Iran and southern California shows that earthquake sequences in Iran, with its 6000-year historical and archaeological record, provide useful case histories for earthquake hazard assessment in the metropolitan Los Angeles region.

Activities at the Scripps Orbit and Permanent Array Center

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The Scripps Orbit and Permanent Array Center (SOPAC) was established to support continuous GPS for the study of crustal deformation in southern California. SOPAC currently maintains and downloads data from 15 of the SCIGN sites (the regional PGGA). The RINEX data from these sites are archived along with data from over 200 other permanent GPS sites in the IGS, CORS, BARD and other permanent GPS arrays. SOPAC also archives precise ephemerides, navigation, raw receiver data, and meteorological data. The capacity of the archive totals over 700 GB allowing all data to be on-line. The total file transfers per month to the GPS community average 40,000 and are increasing steadily. Data processing is carried out with GAMIT/GLOBK software in two steps: the 1st step uses a global network to generate precise orbits/EOP, and the 2nd step estimates regional network coordinates with orbits/EOP tightly constrained. The daily site positions for SCIGN are post-processed to produce time-series for studying the crustal deformation cycle and learning more about GPS error sources. SCIGN related activities at SOPAC are highlighted in this poster, including site maps, time series, crustal deformation results, and a description of SOPAC products.

An Observational Test of the Critical Earthquake Concept

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We test the concept that seismicity prior to a large earthquake can be understood in terms of the statistical physics of a critical phase transition. In this model, the cumulative seismic strain release increases as a power-law time-to-failure before the final event. Furthermore, the region of correlated seismicity predicted by this model is much greater than would be predicted from simple elastic interactions. We present a systematic procedure to test for the existence of critical behavior and to identify the region approaching criticality, based on a comparison between the observed cumulative energy (Benioff strain) release and the accelerating seismicity predicted by theory. This method is used to find the critical region before all earthquakes along the San Andreas system since 1950 with $M \geq 6.5$. The statistical significance of our results is assessed by performing the same procedure on a large number of randomly generated synthetic catalogs. The null hypothesis, that the observed acceleration in all these earthquakes could result from spurious patterns generated by our procedure in purely random catalogs, is rejected with 99.5% confidence. An empirical relation between the logarithm of the critical region radius (R) and the magnitude of the final event (M) is found, such that $\log R \propto 0.5 M$, suggesting that the largest probable event in a given region scales with the size of the regional fault network.

Preliminary Observations on the Geometry of the Whittier Fault from La Habra to Yorba Linda, California and its Kinematic Implications

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The Whittier fault at the surface juxtaposes Mohnian rocks on the north and Delmontian and younger rocks on the south. It generally strikes N65W and dips 70 degrees to the northeast. In the Brea area a restraining left bend of the fault strikes about N72W. Geologic features along the bend include (1) flattened dip on the Whittier fault at shallow depths (Gath, et al, 1992 and Leighton and Associates, 1997), (2) east-west fold axes, (3) steeply dipping and overturned beds and (4) north-dipping proto-Whittier faults. The maximum vertical separation reported for the Whittier fault, also, occurs at Brea. These observations are consistent with right-lateral strike-slip movement in the Late Pliocene and Pleistocene.

Many workers attribute right-lateral offset of Tonner Canyon to movement on the Whittier fault. The south wall of Tonner Canyon at Brea is a prominent hogback that consists of conglomeratic sandstones. The presence of these beds at shallow depths may be related to vertical displacements on the proto-Whittier faults. A small knob on the west end of the hogback may be a klippe of the Whittier fault. Its elevation is consistent with the location of a flattened Whittier fault projected across Tonner Canyon. These relationships suggest that right-lateral offset of Tonner Canyon is not due to faulting but instead reflects the presence of resistant formations.

The Banning Boulders and Other Precarious Rocks in Southern California: Constraints on Ground Motion for the Last Several Thousand Years

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We have recently obtained cosmogenic age dates on the pedestals of several spectacular balanced boulders near the San Andreas fault in southern California. One of the most spectacular is a huge balanced rock about 15 km south of the Banning fault in San Gorgonio Pass (described with photo in Brune, 1996). The cosmogenic age date on the pedestal is 26-30 ka, using a technique that has been cross checked with carbon 14 and rock varnish layering at other sites in southern California. Thus this rock (and several neighboring precarious rocks) have apparently survived many earthquakes on the Banning and Mission Creek strands of the San Andreas fault, and provide important constraints on ground motion from great earthquakes in this region. A geometrical estimate of the quasi-static toppling accelerations is about 0.2 g. Actual field testing of a nearby smaller boulder gives about 0.1 g. A correction for dynamic motions suggests an upper limit of about 0.25 g. On the other hand, typical attenuation functions for ground motions $M=8$ earthquakes give values of mean acceleration of about 0.3 - 0.5 g (mean plus sigma from 0.5 to 1 g), but these are only extrapolations from smaller earthquakes, since no strong motion data are available from great strike-slip earthquakes in southern California. This suggests that precarious rocks may provide critical constraints on seismic hazard calculations for southern California. The results suggest strongly that there is no active south-dipping strand of the Banning fault in San Gorgonio Pass, and perhaps that the Banning strand of the San Andreas fault is not as seismogenic as the Mission Creek branch.

Crustal Deformation Velocity Map of Southern California

Crustal Deformation Working Group
Southern California Earthquake Center

An updated velocity map is obtained using reprocessed and newly processed GPS data. A total of 194 GPS and 223 EDM site velocities are estimated, representing an increase of about 50 GPS sites compared to the current Version 1.0 velocity field. New GPS data includes observation from: LABS 94-97, Inter-county 92, Cholame 89, and Lander 93. Reprocessed GPS data includes: STRC 88-89, HPGN 91-94, Inter-county 93, Gorman 92 and Lander 92.

GPS data are processed using GAMIT and combined together using GLOBK solving for site positions and velocities. A priori coseismic displacement constraints for Joshua Tree, Landers, and Northridge earthquakes are obtained from independent coseismic studies. Velocities of a subset of fiducial sites are constrained using GSFC VLBI solution GLB1014. EDM data were adjusted with loose constraints and then combined with the GPS velocities using JPLS.

The new preliminary solution indicates far-field velocities of about 35 mm/yr, 40 mm/yr, and 46 mm/yr across the San Andreas fault at the Carrizo Plain, Mojave section, and the Coachella Valley respectively. Significant crustal deformation is observed near to the San Andreas fault in Carrizo Plain (See Shen et al. this meeting).

Rapid Visual Screening of Outdoor Areas in Urban Districts for Potential Seismic Hazards

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This procedure is designed to complement the existing ATC-21 Rapid Visual Screening of Buildings for Potential Seismic Hazards, by extending site surveys to evaluate hazards associated with the spaces in-between and around buildings, such as streets, alleys, courts, parking lots, etc. The rapid visual screening procedure (RSP) and documentation format is modeled after the ATC-21 and includes a data collection form, completion instructions, and samples of completed forms that illustrate how the RSP would be applied to different kinds of sites. Research has focused on identifying the kind of information screeners should observe while on site, and investigating how screeners should use information commonly available from city engineering and planning departments to help them identify and interpret potential hazards in outdoor areas. The RSP for outdoor areas contains a rating system developed to rate each element of screening in three different risk types to assist in the understanding of how the elements effect their surroundings during seismic activity. This procedure is to be used in tandem with ATC-21 to provide a more comprehensive screening of potential seismic hazards in urban areas where the safety of pedestrians building occupants may depend upon the availability of outdoor refuge.

EFFICIENT SIMULATION OF CONSTANT Q USING COARSE-GRAINED MEMORY VARIABLES

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Improvements in computing speed have progressively increased the usable bandwidth of seismic wavefield simulations computed with time-stepped numerical schemes (e.g., finite difference, finite element, pseudospectral). As computational bandwidth increases, anelastic losses become increasingly significant for some important applications such as earthquake ground motion modeling, whole earth seismogram simulation, and exploration seismic profile modeling, and these losses need to be included in the simulations. As bandwidth increases, however, the memory variables necessary to incorporate realistic anelastic losses account for an increasing proportion of total computational storage requirements, a consequence of the broad relaxation spectrum of typical earth materials. To reduce these storage requirements, we introduce a new method in which the memory variables are coarse-grained, i.e., redistributed in such a way that only a single relaxation time is represented at each node point (and therefore a single memory variable per stress component is required). Guided by a perturbation analysis, we effect this redistribution in such a way that spatial variability of this single relaxation time simulates the full relaxation spectrum. Such coarse-graining reduces memory-variable storage requirements by a factor of 8 for 3D problems, or a factor of 4 for 2D problems.

In fourth-order finite difference computations for the 3D acoustic wave equation, the method simulates frequency-independent Q within a 3% tolerance over 2 decades in frequency, and is highly accurate and free of artifacts over the entire usable bandwidth of the underlying finite difference scheme. These results should also hold for the elastodynamic equations. The method is readily generalized to approximate specific frequency-dependent Q models such as power laws, or to further reduce memory requirements. In its present implementation, the main limitation of the method is that it generates artifacts at wavelengths equal to 4 grid cell dimensions and shorter, which may, in some limited circumstances, overlap the usable bandwidth of very high-order finite difference and/or pseudospectral schemes.

DYNAMIC STRESS CHANGES DURING EARTHQUAKE RUPTURE

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We assess two competing dynamic interpretations which have been proposed for the short slip durations characteristic of kinematic earthquake models derived by inversion of earthquake waveform and geodetic data. The first interpretation would require a fault constitutive relationship in which rapid dynamic restrengthening of the fault surface occurs after passage of the rupture front, a hypothesized mechanical behavior which has been referred to as "self-healing". The second interpretation would require sufficient spatial heterogeneity of stress drop to permit rapid equilibration of elastic stresses with the residual dynamic friction level, a condition we refer to as "geometrical constraint". These interpretations imply contrasting predictions for the time dependence of the fault-plane shear stresses. We compare these predictions with dynamic shear stress changes for the 1992 Landers (M 7.3), 1994 Northridge (M6.7), and 1995 Kobe (M6.9) earthquakes. Stress changes are computed from kinematic slip models of these earthquakes, using a finite difference method. For each event, static stress drop is highly variable spatially, with high stress drop patches embedded in a background of low, and largely negative, stress drop. The time histories of stress change show predominantly monotonic stress change after passage of the rupture front, settling to a residual level, without significant evidence for dynamic restrengthening. The stress change at the rupture front is usually gradual rather than abrupt, probably reflecting the limited resolution inherent in the underlying kinematic inversions. On the basis of this analysis, as well as recent similar results obtained independently for the Kobe and Morgan Hill earthquakes, we conclude that, at the present time, the self-healing hypothesis is unnecessary to explain earthquake kinematics.

Stress Evolution in Southern California and Triggering of Moderate, Small, and Micro Earthquakes

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We calculate the evolution of stresses in southern California, extending the study of Deng and Sykes [1997] by increasing from 6 to 36 the number of earthquakes for which coseismic changes in stress are computed and by expanding from $M > 6$ to $M > 1.8$ the range of magnitudes M of events whose focal mechanism solutions are examined in the context of the evolving stress field. The cumulative stress on a given date is calculated with respect to an arbitrary zero baseline just before the 1812 Wrightwood earthquake. By taking into account the long-term stress loading associated with 98 fault segments and coseismic stress changes for 36 significant earthquakes, our calculations indicate that more than 85% of $M > 5$ earthquakes from 1932-1995 occurred in regions of positive change in Coulomb failure function (DCFF). Most of the remaining about 15% earthquakes that occurred in areas of negative DCFF fall very close to boundaries between positive and negative DCFF, some of which are sensitive to the less-well controlled slip distributions of the earliest historic events. Calculations also show that from 1981 until just before the 1992 Landers earthquake more than 85% of small ($M > 3$) and micro ($M > 1.8$) shocks in the Seeber and Armbruster [1995] catalog with mechanisms involving either NW-trending right-lateral or NE-trending left-lateral strike-slip faulting occurred in regions of positive DCFF. The ratio of encouraged to all small and micro events reaches a high value of about 88% if an apparent coefficient of friction between 0.0 and 0.6 is used. The highest percentage of earthquakes occurred in areas where stress is about 1 MPa above the 1812 baseline. Most (66%)

events occurred in regions of DCFE between 0.0 and 2.0 MPa. The upper limit indicates that the approximate range of stress variation in the earthquake cycle is of the order of 2.0 MPa. The fact that the locations of most moderate, small, and micro earthquakes are still related to stress changes remaining from large historical events might be used to constrain slip distribution of some of those earthquakes and to constrain the locations of future significant events.

Densification of the SCEC Geotechnical Data Base and its Integration with a Nonlinear Site Response Model in a GIS Environment

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To advance the understanding of the effects of local geologic and soil conditions on the intensity and characteristics of ground shaking and related damages for the area of Los Angeles, and to improve methods for dealing with these effects, a new approach is developed based on modern computing technologies. This new approach contains two components.

(1) computer based 3-dimensional (3-D) geotechnical data base describing the variation of local soil conditions and geology spatially (horizontally and with depth) for the area of Los Angeles, and

(2) a unique geographic information system (GIS) for the calculation of ground motions and related effects for an area of interest obtained by the integration of the geotechnical database and a nonlinear site response model.

The database and the GIS are generated by the software called "Techbase". The geotechnical database is developed by digitizing relevant information from more than 1000 geotechnical boring logs. Such database can be used to generate automatically the maps of average soil properties for selected area and vertical soil profiles between any two selected points. The maps and profiles can be then compared to past earthquake damages or other types of information, and in this way used readily by geotechnical and earthquake engineering professions for the expeditious assessment of the sites of civil engineering structures.

The nonlinear site response model integrated into the GIS is a modified version of the computer model DESRA-2, which is named DESRAMOD-2. The nonlinear site effects can be delineated by such a GIS in the form of various maps, such as the map of maximum ground surface accelerations, maps of spectral accelerations for selected oscillation periods, map of maximum seismic pore water pressures for the entire area regardless of the depth at which the pressures were generated or for a specific depth interval, and maps of accelerations, velocities, displacements, stresses and strains for any given depth interval. The comparisons of such GIS maps show the anticipated correlations between different data and nonlinear site response phenomena. The consistency of such correlations and other data presented in the Ph.D. thesis by the first author M. Doroudian indicate that the developed geotechnical database and GIS have a great potential for advancing the state of practice in seismic microzoning, and thus in the fields of earthquake damage evaluation and prediction, earthquake hazard mitigation and earthquake emergency response.

Pervasive Nonlinear Sediment Response Observed During the 1994 Northridge Earthquake

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We address the long-standing question regarding nonlinear sediment response at stiff-soil sites in the Los Angeles region by testing whether sediment amplification was similar between the Northridge earthquake and its aftershocks. Comparing the weak- and strong-motion site response at 15 sediment sites, we find that amplification factors were significantly less for the

main shock implying systematic nonlinearity. The difference is largest between 2 and 4 Hz (a factor of two), and is significant at the 99-percent confidence level between 0.8 and 5.5 Hz. The inference of nonlinearity is robust with respect to the removal of possibly anomalous sediment sites, how the reference-site motion is defined, and with respect to corrections for finite-source effects. Nonlinearity is also suggested by the fact that the four sediment sites that contain a clear fundamental resonance for the weak-motion exhibit a conspicuous absence of the peak in the strong-motion. Although we have taken the first step of establishing the presence of nonlinearity, it remains to define the physics of nonlinear response, and to test the methodologies presently applied routinely in engineering practice. The inference of nonlinearity implies that care must be exercised in using empirical Greens functions at sediment sites to study large earthquakes.

Fold Scarp Formation Along the Southern Strand of the Oak Ridge Fault: Trench Data from Bardsdale, Ventura County, California

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The Oak Ridge fault is a 40-km-long, steeply south-dipping reverse fault that bounds the southern edge of the Ventura Basin, northwest of Los Angeles. During June and July, 1997 we excavated a paleoseismic trench across a well-defined, 6-m-high, 30-m-wide scarp in an orange grove 3 km south of Fillmore, CA. This scarp is one of a series of *en echelon*, right-stepping scarps that define the surface trace of the Oak Ridge fault in this area. The 43-m-long, 5-m-deep trench revealed only one large normal fault at the base of the scarp and over 100 conjugate oblique-normal faults that display both north-side- and south-side-down displacements. This type of faulting indicates that the scarp is not a classic fault scarp; rather it is a "fold scarp," or monocline. Flat-lying strata at the southern end of the trench give way northward to north-tilted strata that dip parallel to the scarp surface. This warping indicates that the scarp is growing as a fold, presumably above a south-dipping strand beneath the trench depth. This is in contrast with previous data from the excavation of the Bardsdale cemetery scarp, 500 m to the southwest, in which much of the scarp height was due to normal faulting. This fold scarp is the only surface manifestation of the Oak Ridge fault; if there is a younger active strand beneath it to the north, geomorphic evidence must be continuously obliterated by the Santa Clara River.

Pre-Upper Miocene Structure of the Western Los Angeles Basin: Implications for Strong Ground Motion

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The base of the upper Miocene Puente Formation marks the largest velocity contrast in the Los Angeles (LA) basin. Our map covers the basin west of a line connecting Las Cienegas, Dominguez, and onshore Wilmington oil fields. West of the Newport-Inglewood fault and south of the northern LA fold-thrust belt, this is the top of Catalina Schist basement. Elsewhere, it is the top of Topanga Formation, which consists of indurated clastic strata and basaltic volcanic rocks. The Topanga is of unknown thickness within the fold-thrust belt and beneath the LA trough; we chose to present data on what is known rather than what is speculated. The map shows wide variability along strike. For example, Tom Wright's Brentwood cross section, used to infer a lens focusing of Northridge earthquake waves to produce greater damage along I-10 in northern LA, is valid only for Brentwood and does not apply to Santa Monica or Sawtelle-Cheviot Hills. Vertical relief between the LA trough is great at Inglewood but much less at Potrero and Rosecrans to the southeast. These variations show the complexity of the surface and the importance of modeling ground motion using 3D geometry for wave propagation.

We first contoured the surface using well and surface control. The contoured data were then used to create an XYZ dataset by triangulation (TIN), which was then iteratively densified and adjusted to honor the original data and geological interpretation. The densified TIN was then gridded with a continuous-curvature splines-in-tension algorithm. We present a video "fly-through" of the gridded basement surface. The data will be available on our website at <<http://pandora.oce.orst.edu>> We seek insights from Group B on the most useful format to present the data. Funds will be requested to complete the LA basin map and to map the San Fernando Valley.

UPLIFT AND EARTHQUAKE POTENTIAL OF THE SAN JOAQUIN HILLS, ORANGE COUNTY, CALIFORNIA

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The San Joaquin Hills (SJH) are a northwesterly elongated anticlinal structure. A suite of at least eight emergent Quaternary marine terraces is present along the coastal margin of the SJH. The SJH coastal terraces correlate with terraces on Newport Mesa, and with terraces further inland along Newport Back Bay, an antecedent but abandoned course of Santiago Creek or the Santa Ana River. The ages of late Quaternary terraces are constrained by amino acid racemization, zoogeographic faunal analysis, and U-series dating of fossil solitary corals. Preliminary analyses of terrace ages and shoreline elevations yield late Quaternary uplift rates of approximately 0.2 - 0.3 mm/yr, consistent with previous estimates of 0.25 mm/yr uplift during the last 0.08-1 Ma (Barrie et al., 1992). Elevated Holocene-age terraces within Newport Bay and incision of coastal drainages in the SJH suggest that uplift has occurred during the Holocene. Karl Mueller is preparing structural models of a plausible blind thrust fault source based on preliminary dates and correlations of late Quaternary terraces and shorelines.

Analysis of Long Period Ground Motion Variability Related to Uncertainty in the Los Angeles Region 3D Velocity Model

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One of the objectives of SCEC is to develop integrated 3D velocity and subsurface structure models of the Los Angeles basin region. While there has been important progress toward this goal, there still remains significant uncertainty in the current models and hence it is necessary to validate these models and quantify the uncertainty they introduce when predicting "scenario" earthquake ground motions. We have already calculated ground motions in the LA region for the Landers earthquake using the proposed 3D velocity models of Graves, Hauksson and Haase, and Magistrale et al. Major differences in the models include the velocity of the

assumed background media, the depth of the Los Angeles basin, and the depth and geometry of the smaller basins. While the general ground motion characteristics are matched by all of the models, significant shortcomings exist in the overall patterns of amplification and the duration of the response. We are now extending this analysis to include simulations of the 1987 Whittier Narrows and 1994 Northridge earthquakes. The goals of this work are 1) to understand the variability in predicted ground motion response related to uncertainty in the 3D velocity models, 2) to evaluate which features of the models are well resolved through the modeling of recorded data, and 3) to refine these models in order to reduce the uncertainty in ground motion prediction for future earthquakes.

ACTIVE SEISMIC SOURCES AND RATES OF DEFORMATION IN THE SANTA BARBARA FOLD BELT, WESTERN TRANSVERSE RANGES, CALIFORNIA

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In the Santa Barbara fold belt, the left-stepping, 80 km long, Mission Ridge fault system (MRFS) is the principle, west-striking, south-dipping oblique-reverse fault. The MRFS is subdivided into structural and geomorphic segments that consists of, from west to east, the More Ranch (13 km), Mission Ridge (15 km), and Arroyo Parida-Santa Ana (50 km) segments. Geomorphic mapping along the western MRFS, specifically on the More Ranch and Mission Ridge segments, document evidence indicative of active deformation. The More Ranch segment folds and faults the 58 ka (stage 3c) Ellwood and 45 ka (Stage 3a) UCSB marine terraces yielding a rate of uplift of 1.1 mm/yr, a vertical rate of separation of 0.2 mm/yr, and a rate of dip separation of 0.4 mm/yr. On the hanging-wall of the Mission Ridge segment, several defeated paleochannels and associated windgaps are preserved indicating westward growth of Mission Ridge. Along the Arroyo Parida-Santa Ana segment, active hanging-wall structures include the west-striking Ortega Hill-Loon Point-Carpinteria fault and fold systems and may be the result of active strain deformation stepping southward to the Red Mountain fault.

Subsidiary northwest-striking, southwest-dipping, reverse faults and related folds include the active San Jose-Mesa as well as potentially active San Pedro-Lavigia and Cemetery faults. The San Jose-Mesa fault form the well-expressed Goleta Valley-Mesa anticlines and warp the 81 ka, 102 ka, and 124 ka marine terrace shorelines yielding a rate of uplift of 0.6 mm/yr (Gurrola et. al., 1997). Also, geomorphic mapping of landforms along the Mesa segment suggests active faulting. Identification of active reverse faults and related folds as well as calculating rates of deformation are critical data for assessing earthquake hazards.

URANIUM-SERIES AGE AND RATE OF UPLIFT OF THE MESA MARINE TERRACES, SANTA BARBARA FOLD BELT, CALIFORNIA

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A well-preserved, fossil solitary coral "*Balanophyllia elegans*" was analyzed from the Bathouse Beach fossil site on the first emergent marine terrace on the Mesa anticline. This sample was cleaned and prepared for U-series analysis by the TIMS technique (Chen et. al., 1986). The fossil coral yielded an age of 70 +/- 2 ka with a U_i of 1.164 +/- 0.015 which may possibly reflect minor diagenetic alteration. Therefore, the U-series age is a minimum age for the first emergent terrace on the Mesa anticline and is assigned to the 81 ka (stage 5a) high paleosea level stand. The elevation of the associated shoreline angle ranges is approximately 40 m indicating cumulative uplift of 45 m for the last 81 ka, therefore yielding a calculated rate of uplift of 0.56 +/- 0.04 mm/yr. Additional flights of terraces and associated shorelines are mapped for the 102

ka (stage 5c), 124 ka (stage 5e), and 212 ka (stage 7c) at elevations of 55 m, 80 m, and 120 m. The calculated rates of uplift for these terrace shorelines range from 0.59 to 0.61 mm/yr and indicate a constant rate of uplift of 0.6 mm/yr for the Mesa marine terraces for the last 200 ka.

Static Stress Drop in the 1994 Northridge, California, Aftershock Sequence

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We use time-domain pulse widths to estimate static stress drops for 279 Ml 2.5 to 4.0 aftershocks of the January 17, 1994, Mw 6.7 Northridge, California, earthquake. The stress drops obtained range from 0.02 to 40 bars, with a log average of 0.75 bar. Error bars computed for our estimates are typically a factor of 5, indicating that the 3 order of magnitude scatter in stress drops is not solely a result of measurement errors and that there is a significant amount of heterogeneity in the static stress drops of the aftershocks. Stress drops might be expected to increase with depth, since a fault can maintain a higher shear load at higher confining pressures. We observe an increase in log average stress drop at about 15 km depth, which is statistically significant at the 80% confidence level. The increase is due primarily to a lack of lower stress drop events below this depth, and may be controlled by material properties since the Northridge aftershocks are observed to intersect an anomalously high-velocity body at around this depth (Hauksson and Haase, 1997). An apparent increase in stress drop with magnitude is also observed over the entire magnitude range of the study, although whether this trend is real or an artifact of attenuation of high frequencies in the upper crust is unresolved.

3D MODELING OF A SPONTANEOUS RUPTURE ENCOUNTERING A FAULT STEPOVER

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Most studies that investigate the physics of earthquakes assume, at best, that earthquakes are ruptures on single planar faults. This is in marked contrast to what we know from field observations; most faults are not this simple.

We investigate one type of complexity that occurs in nature, the fault stepover. We use a spontaneous rupture model that simulates an earthquake encountering a stepover to another, parallel, but non-collinear strike-slip fault. The earth's surface is modeled as a free surface, and the (off-fault) material behavior is elastic. We examine conditions that might allow the simulated earthquake to jump stepovers of various widths and overlaps, and conditions that might not allow the simulated rupture to jump. We use a slip weakening fracture criterion.

Most notable among our observations are that the ruptures prefer to jump to points on the second fault that are near the earth's surface. This is especially true for the cases of compressional stepovers, where the jumps only seem to occur to the earth's surface. For dilational stepovers the jumps are also quite shallow, but can occur deeper than for the compressional stepovers. We also investigate how varying the stress drop, initial stress conditions (both along strike, and with depth), fault lengths, and overlaps change the likelihood of a jump.

Geomorphic Indicators of Tectonic Activity Along the Arroyo Parida-Santa Ana Fault, Santa Barbara and Ventura Fold Belts, CA

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The Mission Ridge Fault System is a 70-km long, north-vergent reverse fault comprised of at least three segments. This research is focused on the easternmost segment, the Arroyo Parida-Santa Ana fault (APSA), of which little is known regarding late Quaternary history. Determination of the APSA as active is precluded by the lack of both historical seismicity and deformed Holocene deposits. However, based upon offset fluvial terraces, Rockwell and others (1984) suggest a vertical slip rate of about 0.37 mm/yr for the last 38,000 ybp for this fault east of the Ventura River.

Statistical analysis of stream length-gradient (SL) indices, along with detailed geomorphic mapping, is used to characterize relative activity along the APSA and to place this fault in a regional tectonic framework. Apparent drainage offsets, beheaded fans, and drag folds indicate a component of left lateral displacement. This study also suggests the presence of two additional segment boundaries within the APSA, one associated with a right step, the second located approximately at the Ventura River. The western segment is characterized by little hanging wall deformation and topographic expression relative to the middle segment. There is no significant difference between the SL indices recorded in less resistant rocks on the up- versus down-thrown sides of the fault west of the Ventura River. SL indices from more resistant rocks, however, maintain some remnant tectonic signal; this suggests that while softer rocks have had sufficient time to adjust to deformation, more resistant rocks have not. SL analysis therefore suggests that the fault may be potentially active. The eastern segment is characterized by significant hanging wall deformation and topographic expression, and may separate the Upper and Lower Ojai Valleys.

Improved Regional Three-Dimensional V_p And V_p/V_s Tomographic Models For Southern California

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We use P and S arrival times from 12,000 earthquakes and timed explosions, recorded by the Southern California Seismographic Network (SCSN), to invert for the three-dimensional P -velocity (V_p) and the P and S -velocity ratio (V_p/V_s) in southern California. The starting model is the one dimensional V_p model from Hadley and Kanamori. To include long-wavelength features of the velocity structure, we invert for a model with a sparse grid (40 km, spacing of horizontal grid nodes), interpolate this model to a 20 km grid, and repeat the inversion. Layers of grid nodes are placed at depths of 1, 5.0, 6.0, 12, 15.5, 16.5, and 20 km. The data variance decreased significantly in the gradational inversion. Ample data from recent major earthquake sequences, the rich background seismicity, and the dense station distribution along with controlled sources made the model well resolved, except along the edges, to the southwest in the offshore region, and at depths greater than 25 km.

The model shows significant differences in velocity structure between the major geological provinces in southern California, Peninsular Ranges, Continental Borderland, Mojave Desert, Transverse Ranges, Imperial Valley, and southern Sierra Nevada. One way of characterizing these differences is to map the spatial extent of the different refractors identified initially in the Hadley and Kanamori model. The final 3-D model that has an upper refractor of 6.0 km/s ranges in depth from about 5 km to 12 km below the deepest basins. The 6.7 km/s refractor is present beneath the Peninsular Ranges, the Tehachapi Mountains, and Imperial Valley. The Mojave Desert and the Transverse Ranges lack the 6.7 km/s refractor and thus have lower V_p velocities than predicted by the Hadley and Kanamori model. In most cases the V_p/V_s

ratios are average, except that high V_P/V_S ratios are mapped in the near surface of all three major basins. At depth beneath the Ventura basin the high V_P/V_S and high V_P suggest the presence of ophiolitic assemblages or mid-Miocene volcanics. Beneath Imperial Valley the same pattern is interpreted as reflect thinned crust related to the ridge spreading processes.

Fault Kinematics near a Restraining Bend along the Whittier Fault, Turnbull Canyon Area of the Whittier Oil Field

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A restraining bend in the northeast-dipping Whittier fault, located at Turnbull Canyon, separates contrasting structures in the footwall block. Beds are overturned only north of the bend. South of the bend, the 184 anticline trends more westerly than the fault. The anticline and overturned beds may be the result of compression beginning in the late Miocene continuing into the early Pliocene. The current position of these structures in relation to the restraining bend indicates that the bend might be an old feature of the Whittier fault, developed when most displacement was reverse-slip.

Recent strike-slip on the Whittier fault is accompanied by reactivation of the 184 anticline, causing uplift in the footwall block south of Turnbull Canyon. North of Turnbull Canyon, the Whittier fault is at the range front with no evidence of Quaternary footwall uplift, indicating that the overturned beds are part of an inactive structure.

Recent fault offsets (Gath, 1997) show that south of Turnbull Canyon, recent offsets are on or near the Whittier fault, but to the north, recent offsets are northeast of the Whittier fault, in the Puente Hills. This may be due to the fault straightening itself to bypass the restraining bend. But if so, this movement is too recent to offset conglomerate beds more than a few tens of meters.

Seismic Source Models for Phase III Report

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James Dolan
University of Southern California
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The Phase III Report includes hazard, moment rate, and magnitude distribution calculations for five source models. These span a range of scientifically credible alternatives and address questions from Phase II. Each model is stated as a probability density function, testable after several years. Hazard calculations are stated as frequency of threshold ground motions, so that hazard calculations from any linear combination of source models can be easily constructed. Background data include a historic catalog for magnitude 5 and larger; a fault map and slip rate table; a table of cascade (multiple segment) rupture frequencies, and a geodetic strain rate map.

Model 1 is based purely on the historical earthquake catalog, so it satisfies the historical magnitude frequency distribution exactly. Model 2 assumes a Gutenberg-Richter magnitude distribution truncated at magnitude 8.2, with seismicity determined by smoothing the historical catalog. Model 3 is like model 2 except that the seismicity is proportional to the geodetic shear strain rate. Model 4 assumes characteristic earthquakes using the CDMG/USGS slip rate model, with cascades. Model 5 is like model 4, adapted to fit new geologic and geodetic data. All models agree with the observed moment rate and historic seismicity.

Campaign GPS Data Archive at the SCEC Data Center

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Over the last year we have archived 5622 RINEX GPS Observation files at the SCEC Data Center; there are now a total of 7237 RINEX files at the Data Center, in addition to about 1400 files in an earlier exchange format (FICA). The data span 11 years, starting in the summer of 1986, and represent much of the high-quality "campaign" GPS data collected in Southern California by university groups and by federal, state, and local government agencies. In order to process this volume of data efficiently, we developed special procedures and computer codes that allow us to incorporate all important information from the field log sheets into the RINEX file, produce a cross-index of all RINEX header information, and leave an "audit trail" that documents all stages of the processing. We have created an index that associates every RINEX file with a specific field log sheet among those stored in bound volumes at UCSD. We have also produced an index of geodetic markers (now including over 400 sites) and are currently developing an index between RINEX data files and geodetic markers, to allow implementation of the "seamless archive" concept being developed by UNAVCO. All procedures are fully documented and available for other groups who wish to archive campaign GPS data.

Spatial Aftershock Distribution

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We study the spatial clustering of shallow aftershock hypocenters with respect to focal mechanisms of mainshocks. Several earthquake catalogs are used: the Harvard CMT global catalog, the PDE earthquake list, the CIT/USGS catalog of earthquakes in Southern California, and a catalog of focal mechanisms for all earthquakes in Southern California with magnitude larger than 6, since 1850. In these calculations we need to account for possible systematic bias in hypocenter distribution due to the geometry of seismogenic zones, especially the geometry of subduction zones. We also select only the strike-slip earthquakes from the catalogs to investigate the aftershock clustering in circumstances more favorable for direct observation. We compare the spatial distribution of hypocenters before each strong earthquake ($M_w \geq 5.8$ or $M_w \geq 6.0$) with the distribution during the first 250 days after the earthquake and the distribution for the time interval extending beyond 250 days. If the friction coefficient in the Coulomb criterion is non-zero, one should expect that after a strong earthquake, aftershocks and other earthquakes would concentrate in the direction of the P-axis (dilatational quadrant) rather than in the direction of the T-axis (compression quadrant). Such a correlation for selected earthquake sequences has been pointed out previously for individual earthquakes; however, it has not been established whether such correlation is a general feature of earthquake occurrence. We study spatial earthquake distributions for several choices of focal sphere partition, cutoff magnitude, focal mechanisms of large events, time periods, distance from a mainshock, etc. Although some earthquake distributions are in agreement with a non-zero friction coefficient, other similar distributions produce an opposite pattern, suggesting that the concentration of events along the P- and T-axes is due to random effects. Thus, our results indicate that aftershock sequences do not exhibit a systematic migration of hypocenters: the difference between pre-earthquake and post-earthquake distributions is either positive or negative in the direction of both axes. This result implies that the friction coefficient in the Coulomb law is close to zero.

CAN WE PREDICT LATERAL PROPAGATION OF RUPTURE DURING EARTHQUAKES? GEOMORPHIC INDICATORS OF PROPAGATION OF REVERSE FAULTS

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The objective of predicting direction of lateral propagation of faulting and by inference, propagation of rupture during earthquakes has important ramifications for earthquake hazards reduction. This results because earthquake damage is often most severe in the direction of a propagating rupture (directivity). Anticipating potential direction of fault rupture during earthquakes will allow for better modeling of potential damages to human structures as a result of seismic shaking.

Reverse faulting and folding are intimately related. Although it's difficult to show that buried reverse faults propagate laterally, the folds these faults produce can, given favorable circumstances, provide indicators of the direction of lateral propagation. Determining direction of lateral propagation of faulting is important because it may indicate a preferred direction of rupture propagation during earthquakes. Assuming that buried reverse faults produce overlying anticlines that propagate laterally, then this suggests that the fault itself is also propagating laterally. In order for a fault to propagate laterally it must rupture and displace new ground in the direction of propagation, thus earthquake ruptures would tend to propagate in the same direction as the growth of the fold.

Geomorphic indicators of fold or tectonic ridge propagation as a result of reverse faulting include (in the direction of propagation): decrease in drainage density and degree of dissection ; deformation of younger material ; and development of characteristic drainage patterns (Jackson and others, 1996).

Is the Earth in a Critical State?

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It has been asserted^[1] that earthquakes are not predictable because 1) there is a consensus that the earth is in a critical state, and 2) since efforts at prediction have been unsuccessful up to now, the future is likely to be equally barren. The consensual position adopts the illogical proposition^[2] that, because self-similar, critical state *models* of tectonically driven earthquakes give power law distributions of energies at all scales, it follows that the observation of power law distributions implies that the earth is in a critical state. We separate the population of earthquakes in southern California into two components, namely aftershocks, which are a relaxation of stress imposed by large earthquakes, and tectonically driven earthquakes, which we assume are the residue of the events after aftershocks are removed. Aftershocks themselves have power law distributions of energies, as well as obey the Omori law of rate of occurrence. The residual distribution for tectonic earthquakes is indeed a power law for small earthquakes but has a "spike" that is appropriate to characteristic earthquakes with magnitudes greater than about 6.4. Most of the aftershocks are generated by the largest earthquakes; by comparison, the smaller main shocks do not produce many aftershocks, even when scaled for magnitudes. Thus the distribution of tectonic earthquakes is not self-similar at all scales, and hence southern California is not in a critical state of seismicity; however, it may be in a critical state for political, economic, sociological, ecological, etc. reasons.

^[1] R. J. Geller, D. D. Jackson, Y. Y. Kagan and F. Mulargia, Earthquakes cannot be predicted, *Science* **275**, 1616-1617.

^[2] A. Sornette and D. Sornette, Self-organized criticality and earthquakes, *Europhys. Lett.*, **9**, 197-202, 1989.

Slip in Earthquakes With Many Aftershocks

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We consider the popular model in which aftershocks are assumed to be due to the relaxation of localized high stresses lodged in small, high fracture strength asperities in the rupture plane that are not broken by the main shock; see for example, ^[1]. The asperities cause slip in the main earthquake event to be irregular; the average slip in the asperity region is reduced as the density of asperities increases. However if the asperities have too high a density, they will prevent the main shock fracture from percolating through the inter-asperity spaces. We apply our model of dynamic in-plane ruptures of fracture to the problem of fracture in a surface with a random distribution of unbreakable asperities. We show that the average slip in fractures that succeed in traversing the inhomogeneous region decreases roughly exponentially with asperity density up to the threshold. For the number of M=4 aftershocks that have occurred since the Landers earthquake, traversal is indeed possible and the average slip at the surface in the Landers main shock is not seriously lowered from the asperity-free case. The critical density of asperities for which the plane is impenetrable is close to, but not identical with the percolation threshold for (scalar) 2-D systems. In cases of earthquakes followed by large numbers of aftershocks, the main shock theoretical seismograms are much more complex with much more high frequency energy, than in the cases of events with few aftershocks, thus determinations of stress drops by spectral methods should give higher values for large earthquakes than for smaller ones^[2], under similar tectonic environment.

^[1] T. Mikumo and T. Miyatake, Earthquake sequences on a frictional fault with non-uniform strengths and relaxation times, *Geophys. J. Roy. Astron. Soc.*, **59**, 497-522, 1979.

^[2] L. Knopoff, Is the earth in a critical state?, *Poster at this meeting*.

Do Young Transpressional Plate Boundaries Require Crustal and Subcrustal Lithospheric Roots?

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The Transverse Ranges in Southern California are the result of recent, diffuse transpressional plate boundary tectonics. Back-projection inversion tomography of the Los Angeles Region Seismic Experiment array teleseismic data set indicates that the crust thickens by 12 km beneath the San Gabriel Mountains in the Transverse Ranges. The data also support the presence of the well-known upper mantle high-velocity anomaly which extends ~200 km into the mantle under the northernmost Los Angeles basin and Transverse Ranges, and has been associated with mantle downwelling due to oblique convergence. Simultaneous inversions of array teleseismic travel times combined with Southern California Seismic Network travel times yield high resolution images of subcrustal lithospheric heterogeneity. This is the first documentation that a significant crustal root exists beneath the Transverse Ranges and directly overlies thickened, high-velocity, high-density subcrustal lithosphere, suggesting coupled deformation between crust and mantle. Previous seismic and gravity studies have led to the conclusion that the San Gabriel Mountains do not have a substantial crustal root and that deformation of the crust is independent from that in subcrustal lithosphere. The high-velocity anomaly does not appear to be a large regional structure, but bifurcates beneath the San Gabriel and Santa Susana Mountains. Simple elastic plate flexure calculations suggest that the undeformed lithosphere is relatively thin (<150 km).

We propose a different kinematic scheme for such lithospheric deformation in which localized horizontal compression deforms the crustal and subcrustal lithosphere together, causing

the lithosphere to thicken resulting in crustal and lithospheric roots. The following kinematic model for this young transpressional deformation is based on seismic, gravity, and plate flexure modeling: 1) there is coupled deformation between crust and mantle, 2) horizontal compression forming a crustal root, and the ductile subcrustal lithosphere down into the asthenosphere, 3) thickened crustal and subcrustal lithosphere is adjacent to thinned lithosphere (the L.A. basin has experienced 20-50% stretching during Miocene extensional episodes). This mechanism suggests that an active local effect such as localized horizontal compression rather than a large regional effect such as remnant slab material, controls the location and geometry of shallow lithospheric heterogeneity. We are currently testing this hypothesis in collaboration with Greg Houseman who will be assuming Rayleigh-Taylor instability with crust-mantle coupling and horizontal convergence in numerical simulations.

Amplification Observations from the Ongoing Los Angeles Basin Passive Seismic Experiment (LABPSE) Dense Array

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A high-density array composed of short-period seismometers has been installed across the entire Los Angeles basin for 9 months (March to November, 1997) to image high-resolution crustal and upper mantle structures beneath the basin. The goals of the experiment are to 1) investigate crustal thinning in the Los Angeles basin as suggested by Los Angeles Region Seismic Experiment passive phase teleseismic residuals, 2) relate the tectonic extensional history to thermal models of basin subsidence and stretching, and 3) quantify amplification of ground motion due to variations in sedimentary environments and subsurface structures. We are recording local, regional, and teleseismic earthquakes continuously during the experiment. The teleseismic residuals combined with SCSN data will be used in tomographic inversions for sub-crustal lithospheric heterogeneity with greatly increased raypath coverage and resolution beneath the Los Angeles basin. The three-dimensional images of lithospheric heterogeneity will allow us to evaluate the role of recent tectonics in the geologic history of the eastern Los Angeles basin.

The local events are being used to quantify ground motion amplification in densely populated areas near the Whittier and Sierra Madre faults. Preliminary analysis shows an unexpected change in waveform character between the Puente Hills stations and adjacent stations to the north (San Gabriel Valley) and south (southern Los Angeles basin). Several earthquakes which occurred near the array produced surprisingly impulsive P and S arrivals in San Gabriel Valley and Los Angeles basin records, but scattered or emergent arrivals for stations in the Puente Hills. A defocusing structure such as a sharply folded anticline would explain this observation. In addition, the horizontal waveforms for the basin stations are significantly amplified between Cerritos (south of Whittier) and Cypress (north of Seal Beach), the segment which corresponds to the region of maximum basin sedimentary thickness.

The Self-Organization of Aftershocks

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Models of aftershocks that assume that they are due to irregular slip in the main fracture plane are inadequate to account for the universality of the Gutenberg-Richter magnitude distribution of aftershocks. Since most of the aftershocks occur near the main fault plane in a zone of stress that is reduced from that before the main shock, we must assume that the region

near the main fault surface is heavily damaged by the main rupture. Thus aftershocks arise in a two-stage process: First the adjoining medium is randomly fractured (damaged) by the main rupture in a time scale that corresponds to the travel of seismic waves from the main rupture. The second is the relaxation of the asperities between the microfractures developed in the first stage, on the time scale of the aftershock series. We further assume that the cracks in the damage zone remain open over the entire aftershock sequence^[1].

We model the region near the fault as a 2-D elastic lattice under constant antiplane strain. The lattice is populated by a random distribution of dislocation sites; the strengths of the unbroken bonds can decay by stress corrosion; the unbroken bonds re-establish their strength after an aftershock, i.e. the damage remains permanently in place for the duration of the calculation. The aftershock system organizes itself via the redistribution of the stresses by the aftershocks as an evolutionary process into a state having the properties of the GD-R and the Omori rate laws, with exponents $b \sim 1$ and $p \sim 0.8$. The process is thus universally applicable. The results are robust with respect to a wide range of parameters and only requires that the rate of decay of strength be proportional to the local stress to some positive power. The aftershock series ultimately stops.

^[1] T. Yamashita and L. Knopoff, A model of foreshock occurrence, *Geophys. J. Roy. Astron. Soc.*, 96, 389-399, 1989.

Evaluation of Attenuation Relationships in the Southern California Region

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Regression for empirical attenuation models, which predicts ground motion characteristics as a function of magnitude and distance, is an essential part of seismic design and seismic hazard analysis. Numerous regressions exist. This study selects six of the most recent ones that were judged likely to be appropriate for the southern California region, and attempts to determine which is most successful in predicting ground motions in this region.

For an empirical regression model, most of the constraints come from empirical observations. However, models that include realistic sources and wave propagation also predict some expected characteristics of the regression models. This study thus considers each of the regressions from both theoretical and empirical points of view. To account for the heavily unbalanced recordings for individual earthquakes in the data set, the random effects model (Abrahamson and Youngs, 1992) is used for the empirical evaluation, in which residuals between observations and predictions are partitioned into event-to-event contribution and intra-event contribution and equal weight is given to each event in the statistical analysis.

Site conditions are known to have important effects on ground motions. Regressions are generally specialized for different categories of site conditions. In regression analysis, measurements of site parameters are often considered to be the major way to reduce the residuals of ground motion predictions. In this study, in collaboration with other researchers in the Southern California Earthquake Center (SCEC), we examine some of the proposed site parameters to determine whether detailed site information can help to improve ground motion predictions in the southern California region. Also we calculate the error contributions from source/path and site. We find that in the southern California region, more detailed site information will yield very little improvement in predictions of peak accelerations. Greater improvement is possible at longer periods.

Evidence of Fault Healing after the 1992 M7.5 Landers, CA, Earthquake from Repeated Explosions

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P, S and fault-zone trapped waves were successfully excited by near-surface explosions in the Landers, California, fault zone that was ruptured in the M7.5 earthquake of 1992. The waves were observed in 1994 and 1996 on 2 linear, three-component seismic arrays deployed across the fault trace. The coda-normalized amplitude spectra of the trapped waves show a maximum peak at 1-3 Hz with relatively low frequency for the fault segment containing mainshock epicenter. The explosion-excited trapped modes are similar to those generated by earthquakes but have lower frequencies and travel more slowly. These observations suggest that the fault-zone waveguide is slower and possibly broader around the hypocentral region, and as it approaches the surface. Waveform modeling of explosion-excited trapped waves yields a shallow fault-zone waveguide ~250 m wide where the apparent S velocity is about 1.0-1.5 km/s and $Q \sim 10-20$.

We compared the data recorded in the two duplicate experiments in 1994 and 1996. Using cross-correlation, we find that the travel times of P, S and trapped waves for the same shot-receiver pairs decreased by 0.5-2.0 percent from 1994 to 1996 with the larger changes at stations located within the fault zone, indicating that the fault velocities increased between 1994 and 1996. We interpret that the Landers fault zone have being experienced a healing (strengthening) process after the mainshock due to the closure of cracks which were opened in the 1992 event, and estimate that the apparent crack density within the fault zone was reduced by 0.005-0.01.

Effects of Randomization of Source Parameters for Estimating Strong Ground with Empirical Green's Functions

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The complexity of the earthquake rupture convolved with complex path effects and site response produces the high-frequency strong ground motion. It is difficult to model the detailed source process and wave propagation deterministically in such a way as to reproduce waveforms that match the phase of accelerograms. However, we can avoid these difficulties in the estimation of strong ground motion by randomizing some source parameters and by using small earthquake recordings as empirical Green's functions. We take rupture velocity, rise time, and density of high-frequency radiation on the fault into consideration and describe them as random variables. The probability distributions of these random variables are determined through numerical tests such that the source spectra of large and small earthquakes obey an ω^2 scaling law. The ground motion for a large earthquake is produced by summation of the convolved impulse response with the randomized source parameters of each subfault. This procedure can use all the available empirical Green's functions at a site and can also account for the directivity of the source. This estimation is not biased by a single record, and different possible source-receiver path effects are included. We use this procedure to compare ground motion from the 1994 Northridge earthquake with a suite of ground motion estimates based on randomized source parameters. We have computed average values and confidence interval of peak acceleration, time history envelopes, Fourier amplitude spectra, and response spectra. In most cases the estimated results are in good agreement with the observed strong-motion records.

STRONG MOTION DATABASE AVAILABLE ON THE WEB

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The Strong Motion DataBase (SMDB) at the Institute for Crustal Studies can now be accessed via the World Wide Web (<http://smdb.crustal.ucsb.edu/>). Data continues to be added and the database now includes information from 108 earthquakes, 570 stations, and 3257 traces. The database begins with the 1933 Long Beach earthquake and continues through the 1994 Northridge earthquake, for which recordings from 212 stations are available. Currently the data is predominantly from southern California. In the future, we plan to extend the geographic coverage to include all of California, the United States, and eventually the globe.

Queries to the database from the Web may be made based on numerous parameters such as event name, location and magnitude, station location and owner, peak ground acceleration, response spectral amplitudes at various frequencies, hypocentral and epicentral distances, site geology, and shear wave velocity in the near surface. The traces selected by the queries may be downloaded directly from the site or from other sites via links provided from the SMDB Web site. A Java-based map helps the user to select data. Future enhancements will allow the user to select data directly from the map.

Caltech/USGS Element of TriNet - Current Status

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The Caltech/USGS element of TriNet is an ambitious project to transform the Southern California Seismic Network into a large, digital seismic network capable of recording, archiving, and rapidly analyzing earthquake ground motions in southern California, and capable of rapidly exchanging waveform and derived information with other organizations. The ultimate goals of the project are to improve our understanding of earthquakes and their effects, to contribute to improving building codes and structural designs, and to facilitate emergency response to damaging earthquakes. Since the project began in January of 1997, it has progressed in several areas. Installation of new broadband digital stations, and conversion of short period analog sites to digital instrumentation, has increased the number of real-time digital stations to more than 70 sites and more than 275 continuously telemetered channels. A variety of digital telemetry methods have been adopted to support reliable, low latency telemetry including Frame Relay Service, and spread spectrum radio. The central site data processing system is routinely archiving both low sample rate continuous data and high sample rate triggered data. Real-time earthquake monitoring software has been developed to continuously calculate ground motion parameters using data from the network. Prototypes of special products such as ground motion intensity maps (ShakeMap), paging of peak acceleration measurements to CUBE, and continuous ground motion displays have been developed.

Geology Based 3D Seismic Velocity Models of Populated Southern California Basins

Harold Magistrale
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I present new 3D basin sediment velocity models of the densely populated San Bernardino, Chino, and Ventura basins of southern California, and update an existing model of

the Los Angeles basin area with a new San Fernando Valley model and an improved representation of the southern Santa Monica Mountains. The basin models are constructed in a forward sense by compiling reference horizons of known depth and age for use in a sediment age-depth-seismic velocity relation that is calibrated for each basin. The use of the geologic information provides the fine spatial resolution needed for ground motion simulations, and provides a priori constraints of crustal structure in tomographic inversions of local earthquake travel times.

Probabilistic Seismic Hazard Analysis of Southern California

Mehrdad Mahdyiar
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The focus of the SCEC Phase II report was to integrate all earthquake related information for southern California into a single regional seismicity model. The ground motion hazard from that model was evaluated using the probabilistic seismic hazard analysis (PSHA). The focus of the SCEC Phase III report is to construct different regional seismicity models based on the geologic, geodetic, and earthquake catalog data and to evaluate each model separately using the PSHA. The objectives of PSHA are to conduct such an investigation and to perform scenario studies on various source parameters of the proposed seismicity studies.

Four different seismicity models for southern California are proposed: 1) a fault model based on the earthquake catalog data without any modification; 2) a smooth seismicity model based on the earthquake catalog; 3) a model based on the geodetic data; and 4) a fault model based on the geologic information. The results of the PSHA of these models are presented in the form of maps and cross sections. Models 2 and 3 provide seismicity rates at grid points with the most probable dipping angles and rakes for faults at each grid point. For the grid intervals of 7.5 minutes this would translate to more than 2500 faults in southern California. Special procedures and programs were developed for the PSHA of these two models. For the purpose of cross-referencing the results of the PSHA of this study with those from the USGS/CDMG analysis, a regional seismicity model based on the USGS/CDMG web-site database was constructed. The hazard curves at selected sites, from USGS/CDMG open file reports, show very good agreement with the corresponding USGS/CDMG curves.

Southern California Seismicity -"Real-time", Historical and Educational Products Available on the WWW at the SCEC_DC

John Marquis and Katrin Hafner
California Institute of Technology

The SCEC Education Group has been working jointly with the SCEC Data Center to create new WWW accessible interactive maps, catalogs, animations, and educational modules on seismicity in Southern California. In addition, such SCEC products as the LARSE progress report have also been made available.

Features added this year include: 1) interactive maps and listings of current seismicity in Northern and Southern California; (a mirrored site for Northern California); 2) daily, monthly and yearly seismicity animations based on the SCEC_DC/SCSN earthquake database; 3) an interactive catalog searching mechanism providing data in different formats; and, 4) an interactive educational module (not yet released), which uses data from the SCEC_DC database and SCEC research to teach students about the geographic distribution, rates, and other characteristics of earthquakes in Southern California.

The response to these new features has been high (~15,000 requests/day), especially after such events as the April 26 (M5.0) (89,000 requests) & 27th (M4.9) (95,000 requests) Northridge aftershocks. The continued and increasing interest in these types of "products" indicates that this is an effective way of making SCEC's activities and resources more visible.

Aftershocks of the Great 1857 and 1906 Earthquakes

Aron J. Meltzner

Caltech/U.S.G.S. Summer Undergraduate Research Fellow

David J. Wald

U.S. Geological Survey, Pasadena

As part of a larger effort to understand more about aftershocks to major earthquakes on the San Andreas Fault, we have attempted to "map out" the largest aftershocks of the 1857 "Fort Tejon" earthquake on the southern segment of the fault. We searched through archived first-hand accounts from 1857 through 1862, associated felt reports temporally, and assigned Modified Mercalli Intensities to each site. We then used a grid-search algorithm, derived from empirical analysis of modern earthquakes by Bakun and Wentworth (1997), to find the location and magnitude most consistent with these estimated intensities. Our analysis confirms the conclusions of Sieh (1978) that two foreshocks ("dawn" and "sunrise") on the Parkfield segment shortly preceded the mainshock, and we estimate their magnitudes to be 6 1/4 and 5 3/4, respectively. Preliminary results indicate that, given the size of the mainshock, the aftershock sequence is surprisingly sparse. A similar study will now be done for the 1906 "San Francisco" earthquake, and the spatial and temporal distribution of aftershocks for both earthquakes will be compared, and analyzed in the context of modern seismological insights into stress loading and redistribution as well as fault property heterogeneity.

Use of Evolutionary Strategies to Identify "Critical" Regions to Investigate Seismicity Patterns

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Analysis of space-time seismicity patterns require the choice of a "critical" spatial region and a time window. This choice is typically made on the basis of criteria which are arrived at empirically. This is true in particular for tests of proposed prediction algorithms based on time-to-failure analysis (e.g. *Sornette and Sammis*, 1995; *Bowman and Sammis*, 1996) or Kossobokov and Keilis Borok's M8 algorithm (e.g. *Minster and Williams*, 1996). For such applications, a desirable property of the space-time domain in which the analysis is performed is that the putative signal be as clear as possible. For instance, in so-called "retrospective tests" of a proposed prediction scheme, how does one find the domain for which the test is most successful. This leads to a class of global optimization problems for which the fitness functions are not continuous, let alone differentiable. We show that *Evolutionary Strategies* (e.g. *Fogel*, 1991; *Bäck*, 1996) is an effective approach to solve such problems. A simple example in this class of problems is to find the smallest rectangular region which includes a selected point and N epicenters from an earthquake catalog. We show that this "toy" problem is plagued with issues such as the presence of numerous local optima, and lack of differentiability of the fitness function. Nevertheless, the combination of evolutionary programming and a simulated annealing schedule leads to acceptable solutions with sufficient reliability to be practical.

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**Affects of the Landers Earthquake on Groundwater in Southern California
Seen in the Analysis of Hydrogeologic Signatures**

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SCEC Summer Intern

Hydrologic data from monitor wells, production wells, and springs from both private and public sources were obtained to study the change of hydrogeologic signatures as a function of time leading up to and after the June 28, 1992 Landers earthquake. All the sites in the dilational quadrant of the Landers focal mechanism have measurements of static water level; a site near Palomar Mountain (PM) also includes pH, conductivity, total dissolved solids (TDS), flow, and pressure. A U.S.G.S. monitor well west of San Bernardino, sampling daily, recorded a 0.41 meter change towards the ground surface the day of the Landers. Recovery is approximately twelve days. The low sampling frequency at the other sites was inadequate to ascertain if changes occurred. The weekly sampling frequency of the wells and springs at the PM site, about 100 km from the epicenter, indicates no obvious change in pH, flow, or pressure. However, an increase of approximately 50 $\mu\text{S}/\text{cm}$ and 25 mg/l is seen in conductivity and TDS, respectively. Recovery is reached in approximately fifteen days. The conductivity and TDS data suggests prior to the Landers, no anomaly occurred and that these signatures are possibly related to the earthquake pressure pulse.

**Structural and Geomorphic Characterization of Fault-Related
Folds and Blind Thrust Hazard in the Los Angeles Basin**

Karl Mueller

University of Colorado

Compton-Los Alamitos Trend* Cone Penetrometer Test (CPT) profiles and trench excavations across the projected location of the Compton-Los Alamitos Trend suggest a lack of surface deformation for the last 15-20Ka (i.e. gravels correlated with the Gaspar Aquifer). Evaluation of water well data suggest these flat-lying sediments extend downward to about the Gage Aquifer, tentatively correlated with Stage 9 Interglacial period deposits (~330Ka). The geometry of older sediments imaged on seismic reflection profiles and on cross sections constructed from water well data are clearly deformed in a manner consistent with slip on a NE-dipping blind thrust ramp. These data are interpreted to suggest that the central segment of the Compton-Los Alamitos Trend from the southern Baldwin Hills to the city of Los Alamitos is an inactive seismic source.

San Joaquin Hills** Structural and geomorphic modeling of the northern San Joaquin Hills suggest it is the southern extension of the Compton-Los Alamitos Trend of blind thrusts active in the Late Quaternary. Cross sections of folded Stage 5a-13 marine terrace deposits and maps of stream drainage networks indicate the structure has propagated to the NW in a manner consistent with a simple fault-bend fold developed above a NE-vergent blind thrust ramp. Uplifted antecedent drainages and other landforms in the Newport Back Bay and Harbor areas point to even younger folding (e.g. post Stage 5a), similar to the pattern of deformation seen in older marine deposits. Rates of uplift of the fold are about .25mm/yr. This implies rates of fault slip of $\sim 1.5 \pm .5$ mm/yr for a number of possible geometries for the causative blind thrust. Future classification of the San Joaquin Hills as an active seismic source for Orange County will hinge on either: 1) documentation of recent folding in post Stage 5e deposits in the Newport Back Bay area, or 2) seismic imaging of recent deformation of the Stage 2 erosional unconformity offshore.

East Los Angeles*** Construction of cross sections across the Boyle Heights and City Terrace anticlines indicate these structures form above south-vergent, high-angle reverse faults, and high-level backthrusts as fault-propagation folds. Another potentially active anticline which does not have current geomorphic expression is apparent to the south, beneath recent gravels of the LA River. Repeated section in wellbores suggest the faults which drive uplift of the folds extend to within 300m of the ground surface and dip ~60 degrees north. Correlation of faults between sections suggest the faults terminate at or near the current floodplain of the LA River, limiting their possible link with structures located directly beneath downtown Los Angeles.

In collaboration with

* T. Rockwell, San Diego State University

** L. Grant, Chapman College, E. Gath, ECI, and Roslyn Munro, Leighton & Assoc.

*** M. Oskin and K. Sieh, California Institute of Technology

Accelerated Failure of an Asperity

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At some level of instrumental insensitivity, it is not possible to discriminate between continuous creep and deformation in a series of small earthquakes. Noteworthy among processes that display apparent continuous deformation is accelerated creep in the stages precursory to major ruptures, with implications for prediction of macroscopic breakout. To gain insight into the accelerated process, we use our vane model to simulate the rupture of an asperity as a series of dynamic microevents. We assume that a microcrack once introduced into an asperity, does not heal immediately, but instead remains open until the asperity breaks completely through. At the beginning of the sequence, the sites with the weakest bond strengths break, but these are geometrically isolated from one another; thus these microfractures are independent events with small moment. The process of moment release accelerates as stronger sites break and the fractures not occupy a significant fraction of the asperity; the cracks become more strongly interactive. Stacking the results from a number of numerical simulations shows that the moment release of the unbroken elements in the asperity fits a power-law, which therefore has predictive capabilities.

3D Subsurface Structure of the Ventura Basin: Analysis of Active Fault and Fold Development in Oblique Convergence

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In the Ventura Basin, faults and folds accommodate high rates of oblique crustal strain and uplift rates exceed 10 mm/yr. To improve our understanding of how faults and folds develop in oblique convergence and to evaluate the reliability of 2D models to predict 3D subsurface structure, we have recently acquired a unique 3D dataset for the Ventura Basin provided by the Ventura Basin Study Group (VBSG). The VBSG study consists of 17 structure contour maps and 84 inter-locking cross section data panels based on nearly 1200 correlated deep-penetration wells. The wells vary in depth from 1 to 5 km. Many of these wells drill active fault and fold structures associated with major fault systems, including the San Cayetano, Oak Ridge, and Santa Susana faults. This includes active structures in both the hanging-wall and footwall. This integrated 3D study is based on wire-line logs, mud logs, paleontological reports, core analyses, and surface maps. Each data panel typically ties in 4 directions to define the sides

of a 3D data volume or cell. The result is a 3D presentation of an enormous quantity of high-quality subsurface data that have been reconciled into a coherent geological interpretation. Any 2D or 3D kinematic model of the basin and its associated fault and fold geometry must incorporate these data, if it is to be successful. We hope to continue our analysis of these and other data, and of various 2D models that—to date—have consistently failed to adequately resolve significant subsurface structure in this area. The VBSG structure contour maps and cross sections are now available to the entire SCEC research community from our website at <http://www.crystal.ucsb.edu>.

Resolution of Site Response Issues From the Northridge Earthquake (ROSRINE), Progress Report

**R. Nigbor, R. Pyke, C. Roblee, J. Schneider,
W. Silva, R. Steller, K. Stokoe, M. Vucetic**

The ROSRINE project brings together under one umbrella a strongly coordinated group of geologists, geotechnical engineers and seismologists from a number of organizations to address geotechnical site characterization and ground motion response issues resulting from the Northridge earthquake. The work is co-funded by the National Science Foundation and the California Department of Transportation (Caltrans), with additional funding from PG&E and the Electric Power Research Institute (EPRI). Additional leverage comes from cost-sharing by EPRI, the Southern California Earthquake Center (SCEC), and the U.S. Geological Survey (USGS), and with cooperation from the California Department of Mines and Geology (CDMG). SCEC serves as administrative coordinator for the various co-investigators.

The objective of Phase 1 of this project is the collection, compilation, and rapid dissemination of high-quality site geotechnical and geophysical data for key Northridge Earthquake strong motion recording or structural damage sites. Investigations will include geologic and seismic-velocity logs, e-logs, and collection of high-quality samples for laboratory testing. Since its beginning in August 1996, data have been obtained from more than 25 sites. Phases 2-4 of the project, which include geotechnical model development and site response analyses, are now beginning.

Current results of the ROSRINE project are available on the Web at rccg01.usc.edu/rosrine.

Presenting Author: Robert L. Nigbor, Agbabian Associates, Pasadena

An Integrated Model of the Lower Crust and Upper Mantle from LARSE: Removing Remnant Farallon Slab from Beneath Southern California

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We have created an integrated lower crustal/upper mantle model for Southern California from the Inner Borderland to the Mojave Desert, based on the results from the LARSE 1993 and 1994 experiments. The crustal and sub-crustal structure of the Inner Borderland region is constrained by a two-dimensional velocity model determined from the onshore-offshore data. This model contains a series of dipping layers and a low upper mantle velocity of 7.3 km/sec. This low-velocity material is interpreted to be remnant subducted Farallon slab. The structure of the lower crust under the Transverse Ranges and the Mojave Desert is constrained by an image of a stacked section of explosion data, as well as PmP arrivals on several shot gathers. These results are combined with the high velocity upper mantle anomaly observed by Humphreys and Clayton (1984) and Kohler (1993) under the Transverse Ranges.

The main feature of the integrated model is the coupling of the crust and underlying oceanic slab with the high velocity mantle anomaly beneath the Transverse Ranges. This coupling would explain compression across the Los Angeles Basin and uplift of the San Gabriel Mountains. The model supports the suggestion by Humphreys (1995) that the downwelling material is remnant subducted Farallon Slab. The removal of the remnant Farallon slab by downwelling beneath the Transverse Ranges serves as a model for the post-Laramide removal of the Farallon slab from beneath the western United States.

Active-Source Seismic Imaging Efforts in the Los Angeles Basin

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Analysis of active-source seismic imaging data continued during the past year. We report on the following activities. Results will be shown in the poster display.

(1) Progress was made on the LARSE data processing and analysis. For the Northridge transect, seismic data processing of the offshore MCS reflection profile was completed. Analysis of the onshore-offshore data for the Northridge and the Seal Beach-San Gabriel transects also continued with preliminary velocity structural models obtained. [USC and USGS/MP]

(2) An initial structural model of the San Fernando basin is under development with use of the Chevron seismic profiles. Correlation of reflections with information from well logs allowed for a tentative identification of stratigraphic formations. Contour maps of three horizons were made. Further improvement is anticipated with additional time-depth conversions from sonic log information and velocity information extracted from the seismic data. [USC, SCEC, OSU]

(3) Reprocessing of different industry data sets was performed in order to extract mid- to lower-crustal information via the use of Vibroseis extended correlation. This was in an attempt to identify if sub-basement reflections may be present which could be associated with basement subhorizontal features such as low-angle ramp/flat fault structures. Systematic examination of the raw reprocessed data indicates few deeper reflecting features most visible in the Ventura basin. The low occurrence of reflections is interpreted to be due to factors associated with seismic acquisition and imaging rather than a lack of geological features. [USC and USGS/Denver]

(4) In association with the USGS, a small test was conducted of an alternative source for very high resolution seismic reflection profiling. At the V.A. Hospital trench site in Santa Monica where prior profiling was done by both CSU/Fullerton and the USGS Mini-sosie group, a small CDP profiles was collected using a cartridge-source. Results are similar to the mini-sosie profile, however the acquisition effort is significantly less. [USC]

Site Amplification in the Los Angeles Basin from 3D Modeling of Ground Motion

Kim B. Olsen and Ralph J. Archuleta
University of California, Santa Barbara

We have used 3D/1D 3-sec response spectral ratios to construct site amplification maps for the Los Angeles basin for eight earthquake scenarios (M 6.75 earthquakes on the Palos Verdes, Elysian Park, Santa Monica, Newport-Inglewood faults, approximations to the 1994 Northridge and 1987 Whittier-Narrows events, and two M 7.75 earthquakes on a 170-km long stretch of the San Andreas fault). The individual scenarios show amplification ratios up to an order of magnitude. The distribution of mean response spectral ratios, as calculated from the eight scenarios, has a maximum of 4.1. In general, both the individual scenarios and their mean values show that the largest amplification occurs above the deepest parts of the basin. The largest mean amplification is furthermore associated with relatively small uncertainties ($\log \text{std} < 0.9$ for mean amplification values larger than 3). The largest uncertainties of the mean amplification above the basin ($\log \text{std} 0.9-1.2$) are associated with sites located in the southern and southeastern part. For the eight scenario earthquakes, the amplification tends to increase with distance from the causative fault to the basin structure. The amplification is caused by a combination of effects from the 3D basin and differences in impedance between the 1D and 3D models. The impedance difference effects account for a factor of 2.3 or less, largest above the deepest part of the basin. After correction for the impedance difference effects, the maximum amplification averaged over sites above similar basin structure is about three, associated with sites above the deepest part of the basin. Durations are significantly increased by the 3D basin structure. The largest 3D-1D durations are obtained for the Santa Monica and San Andreas earthquakes, for sites above the deepest part of the basin.

Modeling Dynamic Rupture in a 3D Earthquake Fault Model

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Raul Madariaga
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Ralph J. Archuleta
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We propose a finite-difference method to study dynamic faulting in three dimensions. The method introduces a new implementation of the boundary conditions on the fault which allows the use of general friction models, including slip-weakening and rate-dependent laws, for simulating spontaneous rupture propagation along an arbitrarily loaded planar fault. Our numerical method includes full elastic wave interactions as well as all the usually accepted properties of dynamic faulting, including frictional instability, rupture initiation from a finite initial patch, spontaneous rupture growth and healing both by stopping phases and rate-dependent friction. We use the method to model rupture starting from a localized asperity on a rectangular fault. The shape of the fault is close to circular but tends to become more or less elongated in the in-plane direction. The rupture shows a strong tendency to propagate at super-shear speeds in the direction of in-plane shear, promoted by high initial stresses and small slip-weakening distances. Rate-weakening friction tends to reduce super-shear rupture speeds and generally produces narrow rupture pulses. Comparison of scalar and vector boundary conditions for the friction shows that slip is dominant along the direction of the prestress, with the largest deviations near the rupture front and the edges of the fault.

We have used the method to model the 1992 M_w 7.3 Landers earthquake as the propagation of a spontaneous rupture in three dimensions. The finite-difference method is used to calculate the initial (longitudinal) stress distribution from the slip distribution by Wald and

Heaton. The rupture propagates on the fault along a complex path with highly variable speed and rise time with a duration (22 s) similar to that obtained by kinematic inversion. The dynamic rupture simulation reproduces the general slip pattern used to compute the initial stress distribution, as well as the main features of the low-frequency ground motion for selected stations around the fault.

Deformation Rate and Style Derived from Tectonic Geomorphology: Downtown and East Los Angeles

Mike Oskin and Kerry Sieh
California Institute of Technology

Deformation of a 60 \pm 10ka alluvial surface suggests that 0.7 \pm 0.2mm/yr of North-South contraction is accommodated by folding in East Los Angeles. We use subsurface data from the fault investigation for the Metrorail Eastside Subway, in conjunction with topography and published bedrock geology to document a southward-propagating system of four, East-West-trending, south-vergent, parasitic folds on the south limb of the Elysian Park Anticlinorium. These structures are, from north to south, the Lincoln Heights, Boston Heights, City Terrace and Boyle Heights anticlines. The topographic expression of these anticlines increases southward, whereas the bedrock expression increases northward. The northern two anticlines are characterized by well-developed, asymmetric fold limbs in bedrock, but little or no topographic expression, which suggests that these structures are no longer active. By contrast, the southern two anticlines are characterized by pronounced surface deflection, but comparatively minor bedrock flexure. The highest differential uplift rates are measured at the Coyote Pass Escarpment, an active monocline that forms the southern limb of the City Terrace anticline. Deflection of a 60 \pm 10ka surface by this structure increases smoothly for 6km along strike from 14m at the Los Angeles River to 47m at Laguna Channel. Deflection of the same surface at the crest of the Boyle Heights anticline reaches a maximum of 23m. above local base level. Using area balancing of deformed sediments directly underlying the surface across the Coyote Pass Escarpment, we measure 9.8 \pm 0.5m of contraction accompanied by 17.2 \pm 2.1m of structural relief. This corresponds to a tangent angle of 60 \pm 4 degrees. If we assume that this uplift/contraction ratio is valid in general for structures in East Los Angeles, then we estimate that 39 \pm 7m of north-south contraction has occurred since 60 \pm 10ka. Therefore, we propose that an average rate of 0.7 \pm 0.2mm/yr of north-south contraction is accommodated by folding in East Los Angeles.

PREDICTIONS OF SHEAR WAVE VELOCITIES IN SOUTHERN CALIFORNIA USING SURFACE GEOLOGY

Stephen Park and Scott Elrick
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A new model of the average shear wave velocity in the uppermost 30 m has been generated by extrapolation of discrete velocity profiles using surface geology at several scales. Statistical methods have been applied to create a map that is no more complicated than is supported by the velocity data; several geologic units with similar responses are grouped together. The resulting map is simpler than previous ones and yet fits the observed velocity profiles better than earlier, more complicated maps. Analysis within a geographic information system will permit updates and modification of the map as new velocity data are added.

Modeling the Earthquake Cycle with Dynamic Rupture Followed by Viscoelastic Relaxation

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Inversions of strong motion seismic records in California have proposed that earthquakes preferentially nucleate towards the base of the brittle crust (~15 km), and other studies indicate that post-seismic creep on a fault can account for a significant fraction of the total moment release. We are performing dynamic earthquake calculations for brittle rupture in an elastic crust overlying a viscoelastic half-space to investigate the earthquake cycle. In the dynamical calculation, the final displacement on the fault and maximum depth of penetration of the crack are governed by the form of the stress drop, which is the difference between applied stress just prior to nucleation and dynamic friction. We follow Burridge and Halliday's calculation in which increasing friction at depth (due to overburden pressure) brings a cohesionless crack to rest. On short time scales associated with rupture, we assume the viscoelastic effects are negligible and dynamic friction in the half-space increases with depth as in the brittle region. Thus, during the earthquake, the crack penetrates into the viscoelastic region. On longer time scales, this region undergoes ductile flow to relax the static stress increase resulting from halting the earthquake. This relaxation imposes stress on the locked overlying region, with the greatest amount concentrated at its base, near the brittle-ductile transition. Three stresses constitute the applied stress state: those remaining from the previous earthquake; tectonic stresses; and loading from the viscoelastic region's relaxation. Because the latter's distribution peaks towards the locked zone's base, we expect that with time the overall stress in the lower few km of the brittle crust will increase faster with depth than the breaking strength. Nucleation, which occurs when applied stress exceeds rock strength, will therefore be more likely at these depths. Since the dynamic friction is assumed to increase with depth, the stress drop changes sign. In this model, the limiting depth of earthquake rupture is determined by the depth at which this occurs.

Relocating the Southern California Earthquake Catalog Using the L1-norm and Spatially Varying Station Terms

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We relocate more than 300,000 earthquakes recorded by the Southern California Seismic Network (SCSN) between 1981 and 1997 using an L1-norm, grid-search approach on a smooth 1-D velocity model. Predicted travel times from each of the >200 stations of the network are precomputed to a grid of points covering the region to a depth of 30 km with a 2 km spacing between adjacent points. Events are located by searching for the grid point that minimizes the L1-norm misfit to the archived P and S picks obtained by the network analysts. To achieve finer resolution, we experiment with both linear and higher order interpolation of travel times between grid points. Stations terms are incorporated into the location procedure in several stages. First, we relocate a spatially distributed set of 4,800 events, iterating several times to obtain a stable set of hypocenters and station terms for these events. In this case the station terms are simply the median of the residuals at each station. Next, we relocate the entire catalog of >300,000 events using these station terms. The resulting locations exhibit greater clustering and coherence than the original SCSN catalog locations. The stations terms in this case compensate for velocity differences in the shallow crust below each station, but cannot account for more complicated three-dimensional velocity structure. The next stage is to permit spatially varying station terms by smoothing the residual pattern observed at each station. This technique promises to achieve relative location accuracy comparable to master event methods for large distributed areas of seismicity, which should allow better delineation of fault structures in southern California.

Emergent Shoreline Features in the Santa Barbara Fold Belt, California: Possible Evidence for Holocene Coseismic Uplift Events.

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SCEC intern advisors: L. D. Gurrola, M. A. Trecker, and E. A. Keller

The southern California coastline between Gaviota and Santa Barbara, located within the Santa Barbara Fold Belt, is characterized by marine shoreline features elevated a few meters relative to present day sea level. These include fragmented emergent marine platforms, pholad boreholes and shoreline wave-cut notches. There are three possible hypotheses to the origin of these emergent features: 1) they were formed during a paleo-high stand in sea level, 2) they are the result of erosion, 3) or they are due to a coseismic uplift event. The Holocene paleo sea level curve for southern California shows that sea level has been steadily rising and is currently at a maximum. Therefore, these features which originally form within 1 - 2 m of sea level, are a result of coastal erosion or represent a coseismic uplift event due to a large magnitude earthquake (M 7.0+).

At a few localities, these elevated shoreline features are located 2 to 5 m above high tide. A well preserved uplifted platform at Goleta Point is elevated approximately 1 m above high tide. Pholad bore holes, which are produced within the 1 - 2 m intertidal zone, were discovered at three locations elevated up to 3 meters above high tide. Therefore, it is believed that the presence of elevated pholad bore holes and well preserved emergent marine platforms provide strong evidence of a Holocene coseismic uplift event resulting from a large magnitude earthquake (M 7.0+).

Evolution of Fault Systems at a Strike-Slip Plate Boundary

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Leigh Royden

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Crustal deformation at plate boundaries occurs on and across networks of interacting faults, such as the San Andreas fault system in California. We suggest that within strike-slip settings, part of the complexity in surface strain rate patterns and seismicity is governed by the continuum rheology of the crust, in particular the rheology of the lower crust. We use a model of crustal deformation which incorporates both continuum behavior and localized brittle failure. Faulting in our model is represented by static elastic dislocations imposed at a critical stress threshold. The locations of faults are not pre-specified, allowing us to explore the extent to which the long-term evolution, dynamics and geometry of fault networks are a natural outgrowth of the rheologic structure of the crust. Our results indicate that interaction between a viscously deforming lower crustal layer and brittle failure in the upper crust leads to a heterogeneous stress distribution and complex patterns of surface strain rate and seismicity. In the presence of a low viscosity lower crust, the overall width of the deformation zone increases significantly in time, and encompasses a wide network of interacting faults which surround the plate boundary. Failure histories on these faults are complex, with scattered recurrence intervals arising from long-range, inter-fault interactions.

A POSSIBLE MASTER DECOLLEMENT BENEATH THE SAN GABRIEL MOUNTAINS AND SAN GABRIEL VALLEY: EVIDENCE FROM LARSE REFLECTION DATA

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LARSE reflection data have revealed a bright reflective zone throughout most of the mid-crust of the San Gabriel Mountains (SGM) that dips gently northward from 18-km depth in the southern SGM to 23-km depth in the vicinity of the San Andreas fault, in the northern SGM. The polarity of the seismic signal at the top of this zone is clearly negative, and our analysis suggests the upper 400-500 m of this zone is a low-velocity region representing a velocity reduction of approximately 1.7 km/s. Several factors combine to make the preferred interpretation of this bright reflective zone a young fault zone, possibly a "master" decollement: (1) The top of the zone represents a significant velocity reduction, as indicated above. If the rocks in this zone contain fluids, such a reduction could be caused by a differential change in fluid pressure between the caprock and the rocks in the reflective zone; lithostatic fluid pressure is required at the top of the reflective zone. (2) It occurs at or near the brittle/ductile transition, at least in the southern SGM, a possible zone of concentrated shear. (3) A thin reflection rising from its top in the southern SGM projects to the hypocenter of 1987 M 5.9 Whittier Narrows earthquake, a blind thrust-fault earthquake with one focal plane subparallel to the reflection.

Two-Dimensional Finite Difference Modeling of Two Aftershocks of the 1994 Northridge Earthquake

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Seismological Laboratory, Caltech

Two Northridge aftershocks were modeled with 2D finite difference. One was 4km deep, and the other was 16km deep. Distinctive features in the shallow event data are (a) broad direct S phases at stations in the basin, (b) large amplitude surface waves at stations 8km into the basin, and (c) high-frequency, phase-shifted direct S arrivals at stations beyond the basin. Deep event records are effected less by the basin. The direct S phases are broad in the basin, but instead of surface waves there are small, discrete multiples to direct S. Stations beyond the basin have higher frequency direct S phases, but are not phase-shifted. The features in the data can be explained by a simple basin model and additional structure below the basin. There is a strong contrast in the basin at about 1km depth. The lower basin is relatively transparent, but turns energy from the shallow source up into the basin. The phase-shifted direct S beyond the basin is modeled as a triplication feature consisting of a moderate vertical gradient at 5.5km depth. This study suggests that a strong velocity contrast is needed within the San Fernando Basin and that structures immediately below the basin turn energy sharply up around the basin.

Structural and Seismologic Investigations of Concealed Faults in the Los Angeles Area

John H. Shaw and Jeroen Tromp

Harvard University

We introduce a new, cross-disciplinary effort to define concealed faults and their earthquake hazards in the Los Angeles area using an extensive seismic reflection and sonic log dataset and numerical simulations of 3-D seismic wave propagation. Onshore seismic profiles image blind-thrust and strike-slip faults of the southern Puente Hills that exhibit complex

reactivation histories recorded by growth strata. For example, the Santa Fe Springs thrust, which locally produces fault-plane reflections below 5km, slipped in the early Pliocene but was quiescent through the late Pliocene. Quaternary reactivation of the thrust generated new fault splays and abandoned old ones, demonstrating complex behavior of blind-thrust systems that yield challenges in documenting their recent activity. Regional seismic data define the interactions of these thrusts with other onshore and offshore fault systems. Offshore seismic data, which extend from Santa Monica to San Diego, image significant dip-slip separation across the Palos Verdes fault suggesting oblique slip or strain partitioning. Regional structural models combined with about 200 sonic logs will yield a three-dimensional velocity field for forward modeling of resonance generated by earthquake sources using a pseudospectral technique. Preliminary tests on a 2D transect through the basin clearly illustrate the effects of focusing and site amplification associated with the geometry and velocity structure of the basin.

Geodetic Strain Rates and Fault Deformation Modeling in Southern California

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The Crustal Deformation Working Group of SCEC recently updated its crustal deformation velocity map. The new solution shows significant deformation along the Carrizo Plain section of the San Andreas fault, where the strain appears more concentrated than elsewhere along the San Andreas. The center of the strain pattern lies 10 km east from the surface trace of the fault in the Carrizo Plain, suggesting either displacement of the fault at depth from its surface trace, or continuing postseismic deformation from the 1983 Coalinga earthquake, or consequences of folding in the Elk Hills.

Using CDMG's most recent slip rate estimates as a priori data, we invert the geodetic velocities to obtain interseismic fault slip rates. Except in the Landers area, the data fit the model reasonably well, with normalized post-fit r.m.s. of 2.5. Residual deformation is generally larger in the regions with postseismic deformation from recent earthquakes. Significant discrepancies of fault slip rate estimates between CDMS's and this study are found along the Mojave and San Bernardino sections of the San Andreas fault and along the San Jacinto fault. Such discrepancies might reflect inaccurate geological characterization of fault geometries and slip rates, temporal variations of fault slip rates, or limitations of the elastic dislocation model used to compare the geological and geodetic results.

VELOCITY PROFILE NEAR THE CEMENTOS GUADALAJARA AREA USING SH WAVES

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Steven M. Day

San Diego State University

Using a 24 channel EG&G GEOMETRICS seismograph, a velocity profile was done at the Cementos Guadalajara area in Ensenada, Baja California Mexico to determine the basement depth. The study was done at latitude 31 51.04N and longitude 116 34.79W with an azimuth of N60E. Geophones were placed every 5 meters and the total profile had an extension of 117 meters. A metal plate was used as a source placing it in a hole and impacting it on one end by a hammer, producing SH waves. Register time was 0.5 seconds. A total of 30 velocity profiles were made: 15 direct and 15 reversed profiles. Only stacked records were analyzed. Travel time curves show the presence of 2 layers and we did not find the basement rock for the direct profile, while the reversal profile shows one layer over the granite base rock, indicating a slope <10 degrees from the western side of the profile to the eastern side. Results were compared with a near well log drill and were consistent with the S-velocities for the materials encountered.

Pseudo Green's Functions and Waveform Tomography

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Retrieving source characteristics for moderate-sized earthquakes in sparsely instrumented regions has been made possible in recent years, through the modeling of waveforms at regional distances. The techniques used in such studies model waveforms successfully at long period, using Green's functions for simple 1-D crustal models. For small earthquakes ($M < 4$), however, long period signals are usually noisy and modeling short-period waveforms requires refined Green's functions such as used in the empirical Green's function approach. In this article, we present a new technique that generates such Green's functions by perturbing individual generalized ray responses calculated from a 1-D model. The model is divided into blocks and velocities in the blocks are allowed to vary, which shifts the arrival time of the individual rays similar to conventional tomography. The amplitudes of the rays are perturbed independently to accommodate local velocity variations in the structure. For moderate-sized earthquakes with known source mechanism and time history, the velocity variation in each block and the amplification factor for individual rays can be optimized using a simulated annealing algorithm. The resulting modified Green's functions, Pseudo Green's functions, can be used to study the relative location and characteristics of neighboring events. The method is also useful in retrieving 2-D structure, which is essentially waveform tomography.

SCEC Borehole Instrumentation Initiative

Jamison H. Steidl and Ralph J. Archuleta
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In March of 1997 a workshop was held to discuss the initiation of a borehole instrumentation program within SCEC to be coordinated with other ongoing drilling programs in Southern California. Shortly after the workshop the first year of the program was approved with three borehole sites planned for the first year, and three per year proposed for the three following years. The scientific objectives of this program are: to examine the details of the earthquake source process; to improve our capabilities in predicting the effects of the near-surface soil conditions on ground motion; and, to estimate the degree of nonlinearity for strong ground shaking on typical Southern California soils. Uphole and downhole recordings of earthquakes will be recorded at sites surrounding and within the Los Angeles basin. The data from this project will be transmitted to the Southern California Seismic Network (SCSN) real-time and made available for all interested researchers via the SCEC data center. The first year schedule is for three holes, two on the northern edge of the LA basin at the Griffith Park Observatory, and the Santa Monica Mountains at Stone Canyon Reservoir, and one hole on the south-western edge of the LA basin on the Palos Verdes Peninsula. The first year sites are still in the permitting phase, with drilling to have commenced at the Griffith Park site by the time of the annual meeting. As an example of the project and type of data collected, we will present uphole and downhole recordings from the UCSB campus under a UC funded project. Like the SCEC project, these data are transmitted real-time to the SCSN and available from the SCEC data center for all interested researchers.

SCEC Phase III Report: Chapter 5 - Site Response

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Norm Abrahamson

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Predicting ground shaking from future earthquakes is typically accomplished by using existing empirical attenuation relations for a specific soil type, and a regional earthquake source model, as was done in the SCEC Phase II report. Specifically, an attenuation relation provides an estimated mean value and standard deviation for peak ground acceleration (PGA) or response spectral acceleration (RSA). The standard deviation represents the uncertainty in the predicted ground motion due to the scatter of real data about the estimated mean value. Reduction of the uncertainty in the ground motion predictions, that is, greater ability to predict the variation in level of shaking and damage patterns of a large earthquake, is an important objective. Typically, an attenuation relation specifies motions for different soil types, often specified as simply "rock" or "soil". In this part of the Phase III report, we examine whether differences in measurable and mapable local site information, such as surface geology, measured shear-wave velocity, weak-motion amplification factors, and depth to basement have a distinct effect on ground motion. At the same time, we examine several different site response studies based on weak motion, strong motion, and analytical models of site response which include nonlinearity, to determine to what extent these site response models are compatible.

Further examination of the SCEC Phase II report: Is there a moment or seismicity rate deficit, and is there evidence for huge earthquakes?

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We re-examined earthquakes in southern California since 1903, to study catalogue completeness as a function of time, seismicity rate changes, and the balance between seismic moment release and accumulation. We find that the catalogue is not complete for $M \geq 6$ events even since 1903, and at best is complete only for $M \geq 6.4$ since 1850. Few newspapers, the sources for most isoseismal maps, were printed within 50 km of the major faults until about 1875. We obtain a regional b value very close to 1.0 for $M \geq 6$ seismicity since 1903. On a decade-by-decade basis, the number of $M \geq 6$ earthquakes does not depart significantly from a Poisson process throughout the 20th Century; thus no decade-long earthquake deficits or surpluses can be distinguished. The greatest variations in the decade rate are associated with the three largest earthquakes in the catalogue, the 1927 $M=7.1$ Lompoc, 1952 $M=7.3$ Kern County, and 1992 $M=7.3$ Landers events. If we assume that an event similar to the 1857 $M=7.9$ Fort Tejon earthquake has an average repeat time of 150 yr somewhere along the San Andreas fault in southern California, and add the appropriate proportion ($94/150$ times 8×10^{27} dyne-cm) to the 1903-1997 seismic moment release, we obtain an annual moment release rate of 10×10^{25} dyne-cm. The southern California seismic moment accumulation rate contributed by the plate tractions is variously estimated at 8 to 11×10^{25} dyne-cm per year. We thus find no convincing evidence for a deficit in the rate of moment release. Nor is there a basis for infrequent $M \geq 8$ earthquakes in southern California, other than those expected to occur on the principal elements of the San Andreas fault system.

Comparison of Recent Probabilistic Seismic Hazard Maps for Southern California

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Probabilistic seismic hazard (PSH) maps for southern California produced from the models of Ward, the Working Group on California Earthquake Probabilities, and the U.S. Geological Survey/California Division of Mines and Geology show the peak ground accelerations predicted with each model to occur at 10 percent probability in 50 years, and the probability that 0.2g will occur in 30 years, for "rock" site conditions. Differences between the maps range up to 0.5g and 50 percent respectively. We examine the locations and magnitudes of the differences as a basis to define the issues and avenues of research that may lead to more confident estimates of PSH in the future. Our analysis shows that contrasting assumptions bearing on the proportion of predicted earthquakes that are distributed off the major mapped faults, the size of the maximum magnitude assigned to a given fault, the use (or not) of geodetic strain data to calculate earthquake rates, and the choice of ground motion attenuation relation each contribute to the observed differences between the maps.

Spatial Variations in the Shallow Stress Field of Southern California

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Compilation of data on the present stress field in southern California has given us a good background database of compression directions in the region. This includes previously published data on stress directions and magnitudes, and new data that we obtained by study of breakout orientations in drill holes around LA, using oil or gas industry well logs from the public domain. Wherever feasible we included information on the relative magnitudes of the principal stresses, from hydraulic fracturing measurements, inversion of focal mechanisms, and inversion of breakout orientations from boreholes (Zajac and Stock, 1997). We have now analyzed all of the usable wells in the Division of Oil and Gas archives, and used these to map compression directions in the southern California area (Wilde and Stock, 1997; Kerkela and Stock, 1996). These show a generally N to NNE direction of maximum horizontal compressive stress, except locally near the Whittier fault and in the NE San Fernando Valley, where the direction of maximum horizontal compression strikes NW. We recently acquired a few more datasets from oil companies for offshore wells which still need to be analyzed. Major results this year include: 1) modification of our inversion code to minimize the stress differences between the observed and expected breakout orientations. This gives more physically realistic results than the inversion based on observed angular differences which has previously been used by most authors; and 2) inversion of selected breakout data sets from variably oriented, deviated boreholes in the LA region, in order to place constraints on the complete stress tensor. We find that over even small subregions of southern California, the variations in the stress field at shallow depths (the upper 3 km) can be quite significant.

Kerkela, S., and J. M. Stock, Compression directions north of the San Fernando Valley determined from borehole breakouts, *Geophys. Res. Lett.*, v. 23, no 23, p. 3365-3368, 1996. SCEC publication number 342.

Wilde-Ozimec, M., and J. M. Stock, Compression directions in southern California (from Santa Barbara to the Los Angeles Basin) obtained from borehole breakouts, *J. Geophys. Res.*, v. 102, no. B3, p. 4969-4983, March 1997. SCEC publication number 320.

Zajac, B., and J. Stock, Using Borehole Breakouts to constrain the complete stress tensor, *J. Geophys. Res.*, v. 102, p. 10,083-10,100, May 1997.

Oxygen Isotope Stratigraphy as a Means of Correlating Deformed Marine Terraces to Calculate Uplift Rates, Santa Barbara Fold Belt, California

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Dating marine terraces is critical to determining uplift rates and earthquake hazards along tectonically active coastlines. Fragments of faulted, folded, and otherwise deformed marine terraces are abundant along the California coastline, yet few terrace deposits contain the solitary corals necessary for absolute dating by u-series methods. This scarcity of corals requires the development of another means for resolving terrace chronologies. It is hypothesized that stable oxygen and carbon isotopic signatures preserved in marine terrace mollusks and foraminifera will provide a means for correlating terraces of unknown age to those previously dated by u-series methods. Currently, four terraces in the Santa Barbara-Ventura area have been analyzed: the Isla Vista, Santa Barbara Point, Santa Barbara City College (SBCC), and Punta Gorda terraces. The Isla Vista and SBCC terraces have been previously dated by u-series methods at oxygen isotope stage 3a and 5a, respectively. The Punta Gorda terrace has been dated by less precise methods at oxygen isotope stage 3a. Preliminary data suggest that the Isla Vista and SBCC terraces retain distinct isotopic signatures which allow for differentiation between the 3a and 5a terraces. Furthermore, the data indicate that the Santa Barbara Point terrace correlates with the SBCC terrace, and the Punta Gorda terrace correlates with the Isla Vista terrace. As a result, we are able to correlate faulted fragments of the Punta Gorda terrace, which allows for calculation of a slip rate on the Red Mountain Fault.

Stochastic Ground Motion Prediction Based On Observed Statistical Properties of Acceleration Time Histories

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The basic idea of the stochastic approach (SA) is that the ground motion is represented as a windowed and filtered random noise with average spectral content and duration determined by a seismological description of seismic radiation that depends on source parameters and the distance from the site to the source (Hanks and McGuire, 1981; Boore, 1983).

A common practice is to use Gaussian white noise to generate corresponding time series. Contrary to that, we found that the amplitude distribution of observed accelerograms is non-Gaussian (cf., Gusev, 1996). In fact, it is very similar to that obtained by multiplying a uniformly distributed random process by an exponentially decaying envelope. The rate of the decay is chosen to fit the expected duration of ground motions.

Also we worked out a new form of the attenuation filter to simultaneously account for the high-frequency attenuation and the impedance contrast:

$$I * \cosh(\pi * \kappa * f) / (\cosh(2 * \pi * \kappa * f) + I - 1).$$

Here I denotes the impedance contrast between the site and the source material properties, and κ is the high-frequency attenuation parameter (Anderson and Hough, 1984).

The resulting procedure produces realistically looking acceleration, velocity and displacement time series. In the nearest future we are planning to establish a Web site for SA predictions. Users will be able to obtain a set of SA realizations by specifying the following input source and site parameters: magnitude, stress drop, distance, site near-surface shear wave velocity and κ ; as well as the initial seed for the random number generation.

The Alexandria Digital Library: A Spatially Referenced Catalog of Earthquake Resources

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The Institute for Crustal Studies and the Alexandria Project have been collaborating on a Digital Earthquake Resources (DER) library. The Alexandria Digital Library is a distributed digital library for geographically referenced information, and the Institute for Crustal Studies is developing a collection of metadata (data about data) on earthquake information resources and information on local seismic hazards. The resources which will be available include a catalog of the SCEC web site and data center, a set of local seismic hazard information, a set of single fold seismic lines covering California, cross section and well information for the Ventura Basin, and over 15,000 spatially located references from the GEOFREF bibliography. The DER resources are in addition to focus of the ADL, the cataloging and making available of digital spatial data, such as the USGS DRG's and DOQ's, satellite imagery, and digitized aerial photographs. A user accesses the ADL over Internet through a Java-enabled web browser. Users will be able to discover information by selecting a region of interest on a map, and by typing in the keywords for the search. Similar to a library catalog, ADL returns a listing of items within the search area, and displays the =93footprints,=94 or areas, of the items. The user can then browse graphical thumbnails of the items, and download items of interest to the users local computer. At the end of October, the catalog will be available to UC schools at=20 <http://www.alexandria.ucsb.edu/>

Estimation of the Contribution of Aseismic Deformation to Regional Shortening in the Upper Crust of Southern California: Example from the Ventura Basin, California

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The evaluation of seismic hazard requires reconciliation of measured strain and observed seismicity. Recent SCEC studies suggest that deformation rates determined by geologic and geodetic techniques exceed that which can be accounted for by historical seismicity and thus, a deficit of moderate and/or large earthquakes exists in southern California. While possible, this conclusion is not unique because aseismic deformation may have contributed to bulk regional strain. We examined a 14 km-thick section of Cretaceous to Pleistocene sedimentary rocks and associated Mesozoic granites, along five cross-strike traverses in the Ventura basin to evaluate the contribution of aseismic deformation to regional shortening. Our analysis of macroscopic and microscopic pressure solution structures suggest that the entire section from the Cretaceous Jalama Formation through the Pleistocene Saugus Formation shows unequivocal evidence for pressure solution. The pre-folding orientation of bedding-normal pressure solution cleavage for Miocene and Pliocene strata is east-west and subvertical, consistent with regional, Neogene, north-south shortening. Oligocene and older rocks show deviation from development of north-south shortening fabrics which may reflect pre-Miocene deformation. Our field and microstructural observations show that pressure solution was active and may have made a significant contribution to permanent strain in the western Transverse Ranges of southern California.

UPLIFT GRADIENT ALONG THE SIERRA MADRE -CUCAMONGA FAULT ZONE, LOS ANGELES, CA

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S. LINDVALL

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In 1997 we continued our study on the late Quaternary activity of the Sierra Madre-Cucamonga fault zone (SMCFZ) using geomorphic analysis, field mapping and soils chronology. Three localities along the range front were chosen for detailed analysis to determine rates of uplift across the fault zone. Ages of alluvial surfaces that are deformed by cumulative slip on faults were established by radiocarbon dating or estimated using statistical correlation of soil indices to radiocarbon dated soils.

In the vicinity of the 1971 (M 6.7) San Fernando earthquake rupture, cumulative uplift of the hanging-wall block has produced a well defined flight of strath terraces developed by recurrent lateral planation and subsequent incision along Pacoima Wash, Little Tujunga Wash and Big Tujunga Wash. Ratios of scarp heights and age estimates for the two highest surfaces at Pacoima Wash suggest an average uplift rate of ~ 1 mm/yr (Qt4: 27 m in ~ 28 ka; Qt3: 9 m in ~ 11 ka) for this segment of the western SMCFZ. Preliminary surface age estimates of perched terraces in the Big and Little Tujunga Washes suggest similar vertical separation rates.

The Arroyo Seco has incised ~ 30 meters into the Qt3 surface since middle Holocene time and exposed at least one buried, well-developed Pleistocene soil on the footwall block beneath the Holocene deposits. This buried soil is tentatively correlated to the Q6 or Q7 soils and deposits on the hanging wall, thereby placing maximum constraints on the amount of late Quaternary uplift. Thus near Altadena, the active strand of the central SMCFZ has an average vertical separation rate of ~ 0.3 - 0.4 mm/yr, based on scarp height to surface age ratios (Qt6: 4m in the past 14 ka = ~ 0.3 mm/yr; Qt7: up to 50m in ~ 148 ka = ~ 0.33 mm/yr; Qf8: ≥ 63 m in ~ 164 ka $\geq \sim 0.38$ mm/yr), although the rate may be as high as 1 mm/yr when age errors are considered.

Well expressed scarps across late Pleistocene to Holocene alluvial surfaces delineate multiple strands of the eastern SMCFZ near the Day Canyon area. Soil study and radiocarbon analysis across the most recently active strand of the Cucamonga fault zone suggests a minimum Holocene vertical separation rate of about 1-3 mm/yr. Therefore, the vertical separation rate (uplift rate) decreases from about 1-3 mm/yr along the eastern SMCFZ to less than 1 mm/yr for the central SMCFZ and about 1 mm/yr for the western SMCFZ.

As a consequence of the above observations, we joined with a number of other SCEC scientists to develop a new kinematic model for the Los Angeles region to explain the lower than expected shortening rates on the Sierra Madre and related thrusts. As presented below in the abstract of our paper submitted to Nature, we compared the geologic data with GPS data and interpretations and suggest that much of the geodetically observed shortening across Los Angeles can be explained by conjugate strike-slip faulting, thereby de-emphasizing the role of thrust faulting.

ESCAPE FROM L.A.: EXTRUSION TECTONICS IN SOUTHERN CALIFORNIA AND IMPLICATIONS FOR SEISMIC RISK

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We present a new geologic model that accounts for both the high geodetically determined rate of north-south shortening across the Los Angeles region as well as lower than expected slip rates recently observed on principal thrust faults. We integrate the most recent geologic, geodetic, and seismologic data, all of which show remarkable agreement, to demonstrate that a significant component of the shortening is accommodated by east-west crustal escape along known strike-slip and oblique-slip faults. Consequently, the Sierra Madre fault system and blind thrust faults with relatively low slip rates may pose less risk of future earthquakes than is presently believed, whereas other largely unstudied strike and oblique-slip faults may harbor a greater potential for future damaging earthquakes in the heavily populated region.

On the Consistency of Earthquake Moment Rates, Geological Fault Data, and Space Geodetic Strain: The United States

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New and dense space geodetic data can now map strain rates over continental-wide areas with a useful degree of precision. Stable strain indicators open the door for space geodesy to join with geology and seismology in formulating improved estimates of global earthquake recurrence. In this paper, 174 GPS/VLBI velocities map United States' strain rates of <0.03 to $>30.0 \times 10^{-8}/y$ with regional uncertainties of 5 to 50%. Kostrov's formula translates these strain values into regional geodetic moment rates. Two other moment rates, $\dot{\bar{M}}_{\text{seismic}}$ and $\dot{\bar{M}}_{\text{geologic}}$ extracted from historical earthquake and geological fault catalogs, contrast the geodetic rate. Because $\dot{\bar{M}}_{\text{geologic}}$, $\dot{\bar{M}}_{\text{seismic}}$ and $\dot{\bar{M}}_{\text{geodetic}}$ derive from different views of the earthquake engine, each illuminates different features. In California, ratios of $\dot{\bar{M}}_{\text{geodetic}}$ to $\dot{\bar{M}}_{\text{geologic}}$ are 0.93 to 1.0. The consistency points to the completeness of the region's geological fault data and to the reliability of geodetic measurements there. In the Basin and Range, Northwest and Central United States, both $\dot{\bar{M}}_{\text{geodetic}}$ and $\dot{\bar{M}}_{\text{seismic}}$ greatly exceed $\dot{\bar{M}}_{\text{geologic}}$. Of possible causes, high incidences of understated and unrecognized faults most likely drive the inconsistency. The ratio of $\dot{\bar{M}}_{\text{seismic}}$ to $\dot{\bar{M}}_{\text{geodetic}}$ is everywhere less than one. The ratio runs systematically from 70-80% in the fastest straining regions to 2% in the slowest. Although aseismic deformation may contribute to this shortfall, I argue that the existing seismic catalogs fail to reflect the long term situation. Impelled by the systematic variation of

seismic to geodetic moment rates and by the uniform strain drop observed in all earthquakes regardless of magnitude, I propose that the completeness of any seismic catalog hinges on the product of observation duration and regional strain rate. Slowly straining regions require a proportionally longer period of observation. Characterized by this product, gamma distributions model statistical properties of catalog completeness as proxied by the ratio of observed seismic moment to geodetic moment. I find that adequate levels of completeness should exist in median catalogs of 200 to 300 year duration in regions straining $10^{-7}/y$ (comparable to southern California). Similar levels of completeness will take more than 20,000 years of earthquake data in regions straining $10^{-9}/y$ (comparable to southeastern United States). Predictions from this completeness statistic closely mimic the observed \bar{M}_{seismic} to $\bar{M}_{\text{geodetic}}$ ratios and allow quantitative responses to previously unanswerable questions such as: "What is the likelihood that the seismic moment extracted from a earthquake catalog of X years falls within Y% of the true long term rate?" The combination of historical seismicity, fault geology and space geodesy offers a powerful tripartite attack on earthquake hazard. Few obstacles block similar analyses in any region of the world.

Paleoseismic Evidence for two Young Surface Ruptures on the Raymond Fault, Arcadia, Los Angeles County, California

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During July, 1997 we excavated paleoseismic trench across the Raymond fault that exposed a central, south-dipping fault zone, a vertical fault zone to the south, and stratigraphic evidence suggesting the presence of at least one other strand. The northern half of the trench showed horizontal sand and gravel beds and a poorly developed Bt horizon, both of which thicken northward. This thickening must be accommodated by a fault strand north of the trench exhibiting a north-side-up component of slip. Beds in the south end of the trench have been tilted $10^\circ - 15^\circ$ between the central and southern fault strands.

We found evidence for several paleo-earthquakes on the central strand, including at least two that disrupt the A horizon of the surface soil. This strand exhibits an abrupt change from horizontal sands and gravels north of the fault, to a massive southward-thinning sand unit south of the fault. The latter unit, which we interpret as a colluvial wedge, is overlain by a buried A horizon. This unit is in turn covered by a younger colluvial wedge upon which a thin A horizon has developed. Charcoal, soil age analyses, and thermal luminescence dating of several samples should provide age constraints.

Nonlinear Wave Propagation in a Half Space

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We have developed a constitutive model, called "endochronic" (Valanis and Read, 1982) applicable to rock in the intermediate strain regime, i.e., approximately 10^{-6} to 10^{-3} where nonlinear losses, pulse distortion and harmonic generation have been documented in the laboratory. This mode has been fit to a set of laboratory data on Berea sandstones. In this paper we solve the half space nonlinear wave propagation problem using the highly accurate staggered pseudospectral method. Two cases are considered: the free surface of a half infinite medium and the free surface of a layer overlying a half space, in order to simulate the nonlinear response of a surface sedimentary layer. The modeling results show that 1) nonlinear wave propagation from a monochromatic source excites the odd harmonics of the source frequency; 2) there is energy transfer from lower frequencies to a higher frequency band when the medium is excited by a

wideband source (both of these results are consistent with laboratory and field observations); and 3) the transfer function between the free surface and the bedrock is dependent on the source excitation level because of the amplitude-dependent attenuation.

Valanis, K and Read, H.A, *A new endochronic plasticity model for soils*, S-CUBED report, SSS-R-80-4292, San Diego, Calif., 1982

Contrasts in Fault Source Characterization, West and East Ventura Basin, San Fernando Valley, and Los Angeles Basin

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The western Ventura basin is dominated by fast-moving dip-slip reverse faults (San Cayetano, 7 mm/yr; Oak Ridge, 4 mm/yr) in which long-term slip rates are consistent with GPS convergence rates. Strike slip is external to the basin on the Santa Ynez and Malibu Coast faults. The east Ventura basin is also dominated by dip-slip faults with subordinate strike slip on the San Gabriel fault (1.3 mm/yr). However, the long-term rate matches the present strain regime only for the blind Northridge thrust (1.7 mm/yr), based on its Saugus and Sylmar forelimb basins. The Frew, Torrey, Ward, and Roosa reverse faults and blind reverse faults at Newhall-Potrero and Pico anticlines and near the younger Holser and Del Valle faults became inactive at the end of the Pliocene, prior to Saugus deposition. The Santa Susana fault, across which 5-6 mm/yr dip slip is accommodated, began only 0.6 m.y. ago. The San Fernando Valley is also dominated by dip slip on the Northridge Hills and Mission Hills faults, which merge east to the Verdugo fault, and on the Santa Susana range-front fault. The north-dipping blind fault generating the Santa Monica Mountains uplift has a slip rate <0.5 mm/yr.

In contrast, the Los Angeles basin is dominated by strike-slip faulting: Whittier and Palos Verdes faults, each with 3 mm/yr, Inglewood fault, with 0.5 mm/yr, and several strike-slip faults with unknown slip rates (Hollywood, Raymond, San Jose, Chino). Dip-slip faults have lower slip rates, including the Los Angeles (Las Cienegas) and blind reverse faults beneath Elysian Park folds in east Los Angeles. The Compton-Alamitos ramp-flat thrust, if present at all, appears to be inactive for the last half million years. Blind reverse faults beneath Montebello, Whittier, Santa Fe Springs-Coyote, Richfield-Kraemer, and Peralta Hills appear to be generated by western splays from the Whittier fault, consuming right slip northward. In a similar fashion, the Dominguez Hills and Cheviot Hills anticlines and Rancho reverse fault consume right slip northward on the Inglewood fault. Motion on the Whittier fault is now almost pure strike slip, but in the Pliocene, it was dominantly dip slip.

Pliocene strata in the west Ventura basin and Pleistocene strata in the east Ventura basin and San Fernando Valley have undergone clockwise rotation. Miocene and younger formations in the western Transverse Ranges rotate clockwise at a rate consistent with GPS and VLBI observations.

Late Holocene Paleoseismicity and Slip-Rate of the San Gorgonio Pass Fault: Implications for Through-Going San Andreas Rupture Events

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Two trench sites excavated across the San Gorgonio Pass fault near Cabezon show evidence for multiple, Late Holocene rupture events, an uplift rate of ~2 mm/yr, and a minimum slip-rate of 5.7 ± 0.8 mm/yr resolved parallel to N45W-S45E. The uplift- and slip-rates are average values for the last 1600-1860 years. The exposed faults are oriented N45W, 40-45° NE at the dextral, strike-slip site, and E-W, 25-30° N at the right-oblique, thrust site. These

orientations support the interpretation that the San Andreas fault system in this region consists of a diffuse, 10 km wide zone of dextral shear bounded on the south and southwest by left-stepping strike-slip and thrust faults (Yule and Sieh, 1996 SCEC Annual Meeting abstract).

The trenches show stratigraphic and structural evidence for two distinct rupture events at both trench locations. Charcoal fragments are abundant from both sites, but none have been processed from the strike-slip trench. Charcoal from the thrust trenches constrain the two most recent events to have occurred post-AD 1305-1430 and pre-AD 1655-1950 (2σ calendar C14 ages). Because no historic record exists for a large earthquake in San Geronio Pass, the two events must have occurred prior to ~AD 1775. This equates to a maximum recurrence of 470 years for two most recent events.

No clear evidence exists for pre-AD 1305 events. However, older events seem likely given the <470 year recurrence for post-AD 1305 events, at least 3300 years of stratigraphic record in the trench walls, an observed increase in the vertical separation of strata with depth, fault slip which ends at sub- I and II event horizons, and increased fold amplitude with depth.

Implications. A **maximum** recurrence of 470 years for the last two events at Cabezon does not preclude the possibility of large San Andreas type ruptures carrying through San Geronio Pass. In fact, the two most recent events at Cabezon appear to have occurred during the same time period as the two most recent events at Indio. However, the alluvial stratigraphy at Cabezon makes correlation of these events highly unlikely. A **minimum** uplift rate of 2 mm/yr can account for 1 km of uplift in the hanging wall block of the San Geronio Pass fault over the past 500,000 yr. A **minimum** slip-rate of 5.7 +/- 0.8 mm/yr accounts for about one third of the "missing" San Andreas slip in the Pass.

Trapped Waves along Basin Interface and Its Implication to High Frequency Wave Propagation

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We seek to develop and apply a simplified method that characterize differences between observations or 3D synthetics and the straightforward predictions of a reference genetic model. We use a simple geometrical ray method to study the problem. One characteristic of basin response is that the trapping of waves inside the basin produces long wave duration and excites resonant frequencies. These resonant frequencies or modes are a function of the basin geometry and the excitation of those modes depends strongly on the direction of wave propagation. For instance, waves with shallow incidence angles will be more efficiently trapped inside a basin than waves that come at higher angles of incidence because it is easier for the reflected wave to reach its critical angle of reflection at the lower basin boundary. The total attenuation of this trapped wave train is governed by the intrinsic and scattering attenuation of waves traveling inside the basin and by how effective those waves are re-transmitted out of the basin. All these are well described by a multiple reverberation of rays inside the basin and the wave amplitudes are obtained using the Gaussian Beam method to sum up the contribution from each ray assuming a constant beam width for each ray as it propagates. The results agree with more precise numerical methods and reproduce very well the resonant frequencies and shape of the wave train.

At the edge of the basin, numerical results differ from that of the above simple ray tracing approach. We found the difference is not due to simple reflection at the wedge of the basin as many people would expect. Instead it is caused by the trapped Stoney type waves propagating along the basin boundary that are excited by the incident waves to the basin as well as the reflected waves from the basin. The attenuation of this trapped basin boundary wave strongly depending on the curvature of the basin boundary and its wave length in addition to the intrinsic and scattering attenuation. In particular, it favors the high frequency trapped waves since its wave length is so short that it propagates along the basin boundary much like the Stoney wave propagates along a flat layered interface of the crust.

Our simplified approach to evaluate basin response appears to be very promising, giving the advantage of its faster computation, higher frequency description of the basin wave propagation, and a better understanding of the underlying physical processes of the problem. It is asymptotic to the flat-layered solution where that is appropriate, and to the strictly numerical approaches like finite element or finite difference models that can only be applied at lower frequencies due to computer limitations.

The 1994 Northridge Earthquake: Seismic Tomography and Temporal Stress Rotation in the Source Area

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We have determined high-resolution tomographic images and investigated the state of tectonic stress in the source area of the 1994 Northridge earthquake using a large data set of arrival times and P-wave polarities from the Northridge aftershocks and other local earthquakes. We found that regions with high aftershock activity are generally associated with faster velocities. The velocity is high around the main south-dipping fault of the 1994 Northridge earthquake and the north-dipping fault of the 1971 San Fernando earthquake. A linear distribution of strike-slip aftershocks was found along a NE-SW boundary between high-velocity and low-velocity structures. To the west of this boundary a cluster of large shallow aftershocks with mixed mechanisms occurred in or near the border of a low-velocity area, while to the east aftershocks with thrust mechanisms occurred in a high-velocity area. The results indicate that lateral variations of crustal properties are closely related to the fault segmentation in the Transverse Ranges.

We also found a significant temporal changes of stress orientations induced by the Northridge earthquake. The principal pressure P -axis is oriented $N32^{\circ}E$ from 1981 to June 1992, and $N30^{\circ}E$ from 28 June 1992 to 16 January 1994, suggesting that the stress field in Northridge was not affected by the 1992 Landers earthquake. During the two weeks following the Northridge mainshock, the P -axis is oriented $N13^{\circ}E$, which is a significant (17°) change from that before the earthquake ($N30^{\circ}E$). Between February 1994 and August 1995 the P -axis orientation changes from $N18^{\circ}E$ to $N26^{\circ}E$, and finally ends up at $N34^{\circ}E$ by the end of 1995, which is close to that before the Northridge earthquake. These results suggest that the stresses rotated coseismically, then rotated more slowly back to their original orientation. The aftershocks caused by the mainshock changed the stress distribution in the crust, which showed up as a regional stress change. The temporal stress rotation may imply the existence of inelastic processes in the rupture zone, e.g., fluids. The stress recovery appears to have completed within two years after the mainshock, which is very short compared to the time scale of the earthquake cycle.

