SOUTHERN CALIFORNIA EARTHQUAKE CENTER

SCEC

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UNITED STATES GEOLOGICAL SURVEY

2001 SCEC Annual Meeting

September 23-26, 2001

Proceedings and Abstracts

Embassy Suites Mandalay Bay
Oxnard, California

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Southern California Earthquake Center

2001 Annual Meeting

"The Transition from SCEC1 to SCEC2"

September 23-26, 2001

Embassy Suites Hotel

Oxnard, California

Sunday, September 23

1:00	ITR Working Group Meeting		Tom Jordan
3:30	Break		
4:00	3-D Code Validation Group Meeting		Steve Day
5:00-9:00	Poster Session Set-Up		
6:30	Icebreaker		
8:00	SCEC1 Advisory Council Meeting		Bob Smith

Monday, September 24

8:30	Welcome and Introduction		Tom Henyey
8:45	Agency Perspectives	NSF	Jim Whitcomb
		USGS	John Unger
		CDMG	Jim Davis
9:30	Advisory Council Perspectives		Bob Smith
10:00	Perspectives on PEER/SCEC Collaborations		Jack Moehle
10:15	Break		
10:30	The Highlights Volume		Tom Henyey
11:00	Reports from SCEC1 Group Leaders		Dave Jackson
			Ralph Archuleta
			Tom Rockwell
			Rob Clayton
			Duncan Agnew
			Steve Day

12:00	Lunch		
13:00	Reports from SCEC1 Group Leaders		Continued
14:15	Discussion		
14:45	SCEC1 CEO Summary Intern Introductions		Mark Benthien
15:15	Break		
15:15	Special Invited Talk "The Evolution of Regional Seismicity Between Large Earthquakes" Co-authors: Geoffrey C. P. King and Charles Sammis		David Bowman
16:00	SCIGN Report		Ken Hudnut
16:15	LARSE Report		Gary Fuis
16:30	SCEC Models Shootout		Steve Day
16:45	SCEC1 Budget Status		John McRaney
17:00	Discussion and Questions		
18:00	Dinner		
Evening	Poster Session		
20:00	SCIGN Advisory Council Meeting		Jeff Freymueller

Tuesday, September 25

8:00	From SCEC1 to SCEC2		Bernard Minster
8:15	Overview of SCEC2		Tom Jordan
8:45	SCEC2 Partnerships	IRIS	David Simpson
		CUREE/NEES	Bob Nigbor
		ACES/GEM	Andrea Donnellan
9:45	Break		
10:00	SCEC2 Draft Science Plan		Tom Jordan
10:30	Disciplinary Group Breakouts	Geology	Rockwell/Seeber
		Geodesy	Agnew/Hudnut
		Seismology	Vidale/Beroza
		Rock Mechanics	Tullis/Dieterich

12:00	Lunch	
13:00	Focus Group Meetings	
13:00	Structural Representation	J. Shaw/Clayton
	Fault Systems	Hager/Sammis
15:00	Break	
15:15	Earthquake Physics	Harris/Archuleta
16:15	Seismic Hazard Analysis	Field/Anderson
17:15	Implementation Interface	Somerville/Wesson
16:30	Dinner	
	Awards and posters	
20:00	SCEC Advisory Council Meeting	Bob Smith

Focus groups get act together for Wednesday morning presentations

Wednesday, September 26

8:30	Summary of Priorities from Focus Groups
10:00	Break
10:15	Contents of RFP and How It Will Work
10:30	Time Table and SCEC2 Schedules
11:00	Discussion and wrap up
Lunch	Meeting of Interim SCEC-2 Representatives

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Message from the Directors

To: SCEC Community

From: Bernard Minster and Tom Henyey

Date: September 23, 2001

After 11 years of activities, SCEC is now holding its last annual meeting. By all accounts this has been an extremely successful decade. We have demonstrated not only that scientists from vastly different disciplines and from different institutions can work together effectively, but also that new science can be tackled through this mechanism _ science that could not be contemplated in any different setting.

But instead of a sunset of SCEC-1, this year's meeting should be viewed rather as the sunrise of SCEC-2. As is now well-known, the SCEC-2 proposal was successful – NSF and USGS are funding a continued Center for the next five years.

In addition, two other proposals were funded as well. A proposal to the National SMET Digital Library program, entitled *Electronic Encyclopedia of Earthquakes (E^3)*, and a proposal to the NSF Information Technology Research Program entitled *SCEC Community Modeling Environment.* Moreover, we will continue working with the State of California to find ways to increase State funding as well as strengthen our partnerships with the California Division of Mines and Geology and the Governor's Office of Emergency Services. Hence, SCEC-2 is a much broader activity than its predecessor, even though we have yet to reach the annual funding goals we set for ourselves a year ago.

Therefore, SCEC-2 is a going concern. It will be significantly different from SCEC-1. This annual meeting will highlight the novelty of the new Center, as well as the needed continuity with the past. We will have to work hard on the transition process. Several points need to be noted:

- At the 2000 SCEC annual meeting, the SCEC community asked Tom Jordan to lead the SCEC-2 proposal writing process. He accepted, and led us through three separate proposals. The success of all three proposals mentioned above is a tribute to his talent as a coordinator and to his untiring efforts in the past 10 months. Jordan will be the SCEC Director starting February, 2002.

- SCEC-2 will engage a broader community in Earthquake research than SCEC-1. New *Core* institutions will include MIT, Harvard and Stanford, as well as USGS Menlo Park and USGS Golden. In addition, there are ongoing efforts to strengthen the ties between SCEC and NASA, in particular through JPL. For instance, InSAR is a technology that we are ready to use in an operational sense for earthquake research.
- There will be a greater emphasis on topics that have not been a strong focus in SCEC-1. Prime examples are rock and fault mechanics, and the behavior of fault systems.
- Quantitative numerical modeling, data assimilation, *grid-based* modeling and *grid-based* data management and visualization will move closer to center stage. This means that the "traditional" SCEC community will learn how to interact effectively with the Information Technology communities, ranging from high performance computing to high bandwidth communications. This will require hard work and a forward-thinking attitude.
- We will continue development of interactions with the engineering community. This means that SCEC will delve more into engineering concerns, including the issues of mapping hazards estimates into risk estimates.
- SCEC-2 will operate in the context of a rather different national scientific scene in the solid Earth Sciences. The NSF-led, multi-agency EarthScope initiative, which includes USArray, SAFOD, PBO, and InSAR as its four major components, gives us a much richer backdrop for SCEC goals and efforts. This is a very exciting development in our field. This effort is still maturing, and has yet to overcome several hurdles. EarthScope is important to SCEC, whether it is a new start in the near future or not, because it represents a significant change in the way we conceive and articulate our science.

So this year's annual meeting is a critical point in the development of the next generation of SCEC science. We should look at our legacy, and take pride in our accomplishments of the past 11 years. At the same time we can afford the rare scientific luxury of developing thoughts which are "outside the box", and can engage in exciting visions of the future of earthquake science. We should do just that!

MEMORANDUM on SCEC2

Date: June 26, 2001

From: James Whitcomb, NSF SCEC Coordinator
John Unger, USGS SCEC Coordinator

To: Tom Jordan

Subject: Revised Work Plan and Budget for the SCEC2 Proposal (EAR-0106924)

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It is our pleasure to inform you that your proposal "A Proposal to NSF and USGS for Sponsorship of the Southern California Earthquake Center" (EAR-0106924) has successfully undergone joint review by NSF and the USGS and we intend to recommend support for this effort beginning February 1, 2002. This proposal, often referred to as "SCEC2" in reference to its follow-on relationship to the SCEC Science and Technology Center that is currently in its eleventh and final year, continues what is generally regarded as a highly successful center. SCEC has greatly advanced our understanding of earthquakes and their hazard in the southern California region that represents nearly half of the seismic risk of the entire U.S., according to a recent FEMA study. Results from this review indicate that SCEC2 can be expected to provide similar outstanding contributions to earthquake understanding and hazard reduction.

However, due to funding limitations within our respective agencies, and following recommendations resulting from the review process, we intend to recommend funding that is reduced from the requested levels in the proposal. We intend to recommend a five-year cooperative agreement from each agency that specify the first year's funding as follows:

NSF $2,500,000 USGS $1,100,000.

Subsequent years' funding under the five-year cooperative agreements are anticipated to be no less than this amount but are subject to annual review and availability of agency funds.

Because the anticipated funding recommendations are less than what was requested in the proposal for the first year, we require a revised first-year work plan and budget that matches the above funding levels, and a general five-year plan that assumes no increase in funding with the possible exception of increases for inflation. One purpose of this memorandum is to provide some guidance as to what we feel would be appropriate areas of emphasis and/or reduction of scope.

Revised Work Plan

Attached is a copy of the site review panel report. Generally, our suggestions parallel much of the site review panel's recommendations and the latter should be carefully considered in your development of the revised work plan.

We and the site review panel agree that the science plan, especially in light of the funding reductions, requires a more specific listing of milestones and products for each interdisciplinary focus. SCEC2 management should prioritize these milestones and products on the basis of probable scientific contribution and success toward the goals of SCEC2. Milestones and products should not make up 100% of the plan and room should be reserved for response to significant earthquakes in southern California and scientific discovery that cannot be anticipated.

There needs to be developed a more specific management plan, especially with respect to the mechanism for the decision-making process for use of SCEC2 funds. As part of this plan, we and the panel feel that SCEC2 management should consider the possibility of multi-year funding for efforts that would benefit from stable funding for more than one year at time.

The overall scope of the original science plan is felt to be overly ambitious, at least at the anticipated funding level, and reductions and prioritization of tasks are needed. We and panel feel that the data gathering and related functions should be maintained at a high priority in order to have the data needed for modeling of earthquake physical processes. Expansion into new directions such as rock mechanics and information technology, while very important fields, may not be possible with current resources. However, incorporation of new efforts in information technology would be facilitated if a pending NSF ITR proposal were to be successful.

Education and outreach, following a very successful SCEC effort, is properly emphasized as a high priority in the new proposal. However, the plan proposed is again felt to be overly ambitious. We and the panel recommend a focus on a more limited set of meaningful goals. Resources might be expanded by a strengthening of ties with the USGS-partners' efforts in education and outreach.

There needs to be a high-priority, proactive plan to increase the involvement of underrepresented groups in the management and programs of SCEC2.

Alternate Funding Sources

We complement SCEC2 management in their efforts to broaden their funding base, such as the pending NSF proposal in information technology.

However, the lack of State funding continues to be an important, and sensitive, missing element in the make-up of SCEC and SCEC2 support as emphasized in this and past reviews. We are continually being asked why the State of California, being a primary beneficiary of the center's efforts in a region of high seismic risk, does not share in its funding. Lack of State funding for SCEC is being interpreted by many as an indication that the State holds these efforts and benefits in southern California at a lower priority relative to other earthquake hazard reduction programs that the State supports. We urge you to continue and intensify your efforts in this important matter.

We encourage SCEC2 to explore other sources of support such as NSF/GEO initiatives in diversity and DLESE (Digital Library for Earth System Education), and programs in NSF/EHR directorate.

Annual Report and Site Visit

We will require an annual report due each November 15 consisting of summaries of the previous year's results, problems encountered, and a request for the next year's funding increment. NSF and USGS will schedule an annual joint site visit in early December (just before the AGU Fall Meeting) to meet with management of SCEC2 and discuss the annual report and the next funding increment.

Again, please accept our congratulations. Please feel free to discuss with us any question that you may have about this memorandum or other matters related to the proposal and management of the Center. We look forward to working with you to continue the tradition of scientific excellence and social relevance that the Southern California Earthquake Center has shown.

James H. Whitcomb
NSF Coordinator for SCEC

John Unger
USGS Coordinator for SCEC

SITE VISIT REPORT

Southern California Earthquake Center
University of Southern California

April 10, 2001

OVERVIEW

The Southern California Earthquake Center (SCEC) has been an NSF Science and Technology Center since 1991 and will reach the end of its funding on January 31, 2002. Under new leadership of Professor Thomas Jordan of USC, SCEC is seeking funding for a reorganized earthquake center from the NSF and U.S. Geological Survey. This center, informally named "SCEC2" for the purposes of the new proposal and for this site review, will retain its interdisciplinary nature of studying the earthquake problem in southern California. SCEC2 will continue to bring together earth scientists from many sub-disciplines for the purpose of obtaining a "physics-based understanding of earthquake phenomena in southern California".

The proposed reorganization will shift SCEC away from its original purpose of developing the "master model" of earthquake hazards to one of basic scientific research. Work on the master model reached a logical conclusion over the lifetime of SCEC (here called SCEC1). Scientists in SCEC1 developed new methodologies in studying seismicity, seismicity rates, and regional deformation that were incorporated in probabilistic seismic hazards assessments. The process of solving these problems underlined many areas of basic knowledge that were missing but needed in making more accurate seismic hazards assessments. For example, SCEC1 was fortunate to experience and respond to three major southern California earthquakes - the 1992 M7.4 Landers, 1994 M6.7 Northridge, and the 1999 M7.1 Hector Mines events. Seismological, geodetic, and geological data from these events suggested several new lines of investigation in understanding spatial/temporal interaction of large earthquakes on separate fault segments that could conceivably lead to better earthquake forecasting. SCEC1 also participated in two large refraction/reflection experiments (LARSE I and II) which yielded important information on structure of the crust, particularly the nature of thrust faults bounding the Los Angeles basin and Transverse Ranges. Like any good scientific investigation, many SCEC1 activities naturally revealed new questions to pursue in understanding the nature of earthquakes and their occurrence.

There is unanimous agreement by the committee that SCEC1 was an unqualified success. SCEC1 managed to bring together a diverse and sometimes competing group of scientists from 9 core academic institutions, more than 20 participating academic institutions, the U.S. Geological Survey, and industry to focus on mutual scientific problems associated with earthquake hazards in the region. It would be hard to imagine that the same amount of progress could have been made without SCEC1. SCEC1 also developed an Education and Outreach program filling a regional need by producing earthquake response information and general public education. SCEC accomplishments are many and will not be reviewed in detail since they can be found in other supporting documentation. However, these accomplishments do point towards probable future success of SCEC2 as a viable and dynamic center of solid earth science.

This report is a result of a site visit made by the NSF and USGS visiting committee on March 27 and 28, 2001, to the SCEC1 home institution at the University of Southern California. The review team heard a full day of presentations on SCEC1/SCEC2, participated in a round-table discussion with ~20 SCEC2 participants, and also read copies of the ad-hoc NSF mail reviews with responses from the SCEC2 staff. The panel integrated this material emphasizing strengths and weaknesses of the proposed work and making constructive suggestions for the NSF and U.S. Geological Survey to consider in the event that SCEC2 is funded.

A. INTRINSIC MERIT OF THE CENTER'S RESEARCH

1. Quantity and quality of productivity to date

The community of SCEC1 scientists at core and participating institutions has been very productive, publishing scores of articles in refereed journals as well as annual reports. The SCEC team has made significant advances in earthquake science during the past 10 years and is expected to have a similar impact on the field under a SCEC2. Many of SCEC1's early contributions were derived from the study of the 1992 Lander's earthquake. These contributions include development of a slip model for the earthquake from extensive mapping of its surface rupture, the depiction of its complex faulting sequence from aftershocks recorded by the TerraScope network and portable instruments, the discovery that fault step-overs and segment boundaries block transmission of guided waves, mapping of the co- and post-seismic regional deformation with GPS and InSAR, and evaluation of stress transfer and earthquake triggering within fault systems. Other advances include the development of the "cascading earthquake" model, imaging of the deep structure beneath the Los Angeles basin and the San Gabriel Mountains, recognition that blind thrusts in the region may pose a significant hazard, and observations from paleoseismology studies on the Eastern California seismic zone that large earthquakes may cluster in space and time.

2. Uniqueness of the research contributions within the community

Many of the contributions made by the SCEC community, especially those related to the collection and sharing of large datasets, would not have been made if not for the research coordination and facilitation provided by the center. The collaboration spawned by SCEC is unique in the earth sciences and serves as a model for other regionally-focused research groups.

3. Quality of individual research projects and project plans

The scientific goals of SCEC2 have been placed in a matrix arrangement with major cells representing "focus areas for interdisciplinary research". These include Structural

Representation (of southern California), Fault Systems, Earthquake Physics, and Seismic Hazard Analysis. These areas of research were delimited both on the basis of scientific targets and on the basis of existing personnel within SCEC. As emphasized by the proposal, each scientific focus area is needed by the others for success. Overall, this arrangement is similar to the original master model in that it integrates a large number of efforts into producing a unified understanding of earthquake effects. However, it is clear that new emphasis is on fundamental scientific research rather than producing specific scientific products that can be used in mitigating seismic hazards. Because the new emphasis is on fundamental research, the committee noted that it was sometimes difficult to understand what specific scientific products would be produced and when specific milestones would be reached. However, the committee and external reviewers all noted that the intrinsic intellectual merit of the proposed research was at the forefront of earthquake science.

The SCEC2 scientific framework is centered about the philosophy of generating community-consensus models that are to be used in simulating earthquakes. These models will incorporate data from diverse sources including seismology, geology, and geodesy and will be available to researchers at SCEC2 and elsewhere for testing and refinement. Part of the infrastructure development of SCEC2 will be concerned with using advanced Information Technology for archiving these models and integrating them with, say, wave propagation codes, or regional block models of fault systems. SCEC2 will depend on developing and validating new computational tools for building these models.

The committee considered scientific issues surrounding these models:

Unified Structural Representation, Fault Systems

The science plan of SCEC2 is organized around the development of a Unified Structural Representation (USR) for the purpose of predicting earthquake behavior in southern California. The USR depends on the development and integration of the "Community Fault Model" and "Community Velocity Model." The community models will require input of fundamental data on topography, geology (faults and other geologic features), seismology (earthquake locations, rupture surfaces, wave speeds, and attenuation parameters), and geophysics (strain rates and crustal structure). In addition to organizing the research effort, community models can serve to test sensitivity and identify deficiencies of various data sets.

Strengths

The community model concept is viewed as a strength of SCEC2 and will help to focus the earth science community on the ultimate goal of understanding earthquake hazards in order to reduce loss of life and property damage during future earthquakes. SCEC1 has helped to facilitate data availability and has fomented collaboration and interdisciplinary coordination in earthquake research. SCEC2 promises to do the same and has broadened its range of participants to include scientists at other universities as well as the Menlo Park and Golden offices of the U.S. Geological Survey.

Weaknesses

A major research goal of SCEC2 is to attain a comprehensive understanding of the southern California fault system. Towards this goal, the center plans to take several approaches to system-level modeling, including fault system kinematics, dynamical earthquake simulation, and 3D simulation of time-dependent stress transfer. The proposal lays out a very ambitious research plan. The SCEC2 team is viewed as top-notch and having the appropriate expertise to tackle these problems. A concern of the review panel, however, is that much of the data needed to develop realistic community models are not available, that costs of collecting all the necessary data are not covered by the current proposal, and that modeling methodologies and integration may be extremely difficult to achieve. For example, only a modest effort is planned for the acquisition of new survey-mode GPS data and paleoseismology data which will not be adequate to characterize short- and long-term slip rates on the more than 300 active faults in southern California. Finding the appropriate balance between data acquisition and model development will be critical for the success of SCEC2 and a major challenge for the planning committee.

Recommendations

The review panel felt that the research plan is overly ambitious and that SCEC2, if funded, will have to prioritize tasks and find an appropriate balance between data acquisition, hypothesis testing, modeling of rupture dynamics and ground motions, and development of 3D modeling methodologies. The panel recommends that SCEC2 dedicate a considerable effort in the next few years to the acquisition of fundamental data regarding fault geometries, slip rates, and behavior, crustal structure, strain rates, and earthquake locations, wave speeds and propagation.

<u>Earthquake Physics</u>

Interdisciplinary models in earthquake physics are related to source rupture dynamics and local wave propagation. Large-scale wave propagation computations must be made to simulate and predict the effects of strong ground motions from large earthquakes in the L.A. basin and San Andreas fault system. The usefulness of these computations depends on the veracity of the 3D earth model employed, efficiency of the wave propagation algorithm, and physical representation of the seismic source. Earth model and source geometry will be provided by the Structural Representation focus group. The physical representation of the source will depend on physical models of earthquake rupture determined, presumably, by stress relaxation source models and constitutive laws of crustal fault zone material determined from rock mechanics.

Strengths

This research is at the forefront of strong ground motion simulation. Validated wave propagation codes will be provided to the community for computations and will no doubt find uses in other seismogenic areas. Advancement in stress relaxation source modeling will probably create new inferences on the nature of fault geometry, such as segmentation, and stress in the crust. Progress will be made on simulating and modeling strong ground motion from data currently available from large recent earthquakes. These simulation studies may also suggest ways of modeling 3D structure and improving the Structural Representations element of the focus group matrix. Accurate earthquake simulations will be input to new methods of Seismic Hazards Analysis.

Weaknesses

Although there are a number of lofty goals that would be desirable to attain, the proposal was weak on describing specifically what would be done and when milestones would be attained. The committee understands that there is a bit of a "chicken and egg" dilemma in defining scientific goals before the SCEC2 planning committee and focus groups are formed. Nevertheless, there are a number of issues that can be addressed at this stage in planning.

Useful 3D wave propagation simulations rely on accurate velocity models as well as accurate computer codes. Computational requirements are large for existing simulations (up to 0.5 Hz). Even with today's processors, can many useful simulations actually be performed to yield the number of simulations needed for a scenario calculation? What are the important wave propagation effects that affect strong ground motions in the L.A. basin and how do they depend on source geometry? What are the effects of small structural perturbations on wavefield simulations? What are the effects of topography and other geological features on the wavefield? What other seismic data sources might yield information on structure? Are these data available? What earthquake data sets will be modeled to form a reference set of simulations? Do these earthquakes come from areas analogous to southern California? When will these data sets be chosen? What constitutes successful modeling?

Recommendations

Since much of the research proposed here is open ended, it would be useful for a preliminary focus group to be formed to map out problems and capabilities that exist at present with these kinds of earthquake simulations. Specific data sets should be identified that have importance in verifying the usefulness of this kind of modeling. These earthquake data sets might be an initial community resource in testing simulation and inversion techniques. Existing computational capability should be tabulated with realistic assessments made on the scale of possible problems and what is needed to increase those scales. Specific milestones need to be defined so progress in this area can be measured by all focus groups. For example, it is conceivable that there will be significant computational limitations on the size of these simulations that may make it impossible for this focus group to contribute to refining the Structural Representation. What would be the significance of this to the overall effort? At a minimum, defining specific existing capabilities, desired future capabilities, and specific milestones for attaining those capabilities will help in prioritizing goals for the overall SCEC2 effort.

<u>*Seismic Hazards Analysis*</u>

SCEC1 was initially launched in 1991 with the explicit purpose of constructing the "Master Model", a probabilistic seismic hazard model, for southern California. A series of reports regarding aspects of the model are in print and the last one in the series, a comprehensive study on the model concepts, is in preparation. The first report was prompted by the occurrence of the 1992 Landers earthquake, soon after the founding of the Center; it focused on studying the possible effects of this earthquake on nearby faults and potential for future strong shaking in southern California; it appeared as a SCEC special report. Then reports on probable earthquakes in southern California (Jackson et. al., BSSA, **85**, 379-435, 1995) and site effects for use in probabilistic seismic hazard analyses of southern California (BSSA, Field et. al., **89**,559-578, 1998) were presented in the peer reviewed, premier seismological journal in USA. Currently the final report, the "Regional Earthquake Likelihood Models, (RELM)," is in preparation. The last model differs from the others in the series in that the effects of different source models used in the calculation will be evaluated. The importance of each factor on the resulting hazard estimates will be studied. SCEC1 will culminate in the completion of the RELM.

Using regional (consensus) source models, attenuation relationships, and local site effects in Southern California, SCEC began to estimate ground motion exceedance probabilities, in its probabilistic seismic hazard analysis (PSHA). In the reports, the inputs were evaluated by a group with a wide range of expertise and were clearly specified. The methodology used for estimating the probabilities was also described. These documents have been used by state agencies (e.g., California Division of Mines and Geology - CDMG and Office of Emergency Services), the City of Los Angeles, insurance companies, general public, etc. for various purposes. In these analyses the inadequacies of some of the assumptions in previous analyses were recognized and new concepts introduced. For example, as a result of the Landers studies, the concept of fault segmentation was violated and a "cascading model" was introduced to allow a number of segments to break in sequence, thereby resulting in larger magnitude events. A goal for SCEC2 hazard analysis is to forecast time-dependent perturbations to average earthquake probabilities in Southern California. The work will incorporate results on studies of fault interactions as well as treatment of earthquakes as non-Poissonian processes.

Strengths

For SCEC2, two new approaches will be taken in seismic hazard assessment. Based on the computational techniques developed in SCEC1, ground motion time series will be generated from consensus as well as other models. While the previous studies produce ground motion spectra without phase information, combining time-space dependent dynamic source and wave propagation, seismograms at a site are computed. Below a certain frequency upper limit, this task is certainly feasible now and it will be a significant advance even if the synthetic signal will be band-limited. Empirical methods using small earthquake records will also be used to test whether such syntheses can correctly model ground motions.

The strength of the theoretical accelerogram generation is that prediction of motions can be done for any magnitude and any site. The empirical methods can potentially overcome this shortcoming of band-limitation of the theoretical methods. The strength for the time-dependent analysis, if it works, is that it will help minimize seismic design costs.

Weaknesses

Common to all integrative efforts, the result is only as good as the quality of the multiple inputs required. The input to PSHA, i.e. the southern California fault model (the geometry, the recurrence rate, the existence of blind faults, etc.), the attenuation model, as well as the site conditions will not be completely known for years to come. The gently dipping fault under Los Angeles as depicted in proposal Figure 2.10 has very important consequence in terms of risks; how can it be confirmed? The attenuation curve and the heterogeneities under the basin will determine the amplitude and duration of shaking; how can they be mapped in detail? The RELM is a starting point for identifying which factors require further intensive studies.

A weakness in using wavefield simulations to estimate strong ground motions is that the procedures to utilize such results in engineering practices have not yet been developed. Even so, for more critical facilities and for future designs of large structures, such input is necessary.

Recommendations

There are significant uncertainties in addressing the seismic hazards of the LA basin and hazard analysis in general. Several opportunities may arise where these uncertainties can be adequately addressed. The USArray proposal can help resolve source structures and heterogeneous velocity and attenuation structure under the LA basin. However, these programs may not come online at the appropriate time, so the success of the hazard research can only be assured through reapportioning center resources. The panel recommends that the center prioritize resources carefully with the view of addressing critical uncertainties in hazard analysis.

Large (M>7) earthquakes occur infrequently in southern California. However, several large, well-recorded earthquakes have occurred in other countries within the last three years. These events may be close analogs of events expected to occur in the LA Basin. Using data from these earthquakes may accelerate the process of validating methodology in achieving reliable hazard estimates for southern California. SCEC2 should develop a more concerted effort in foreign cooperation on hazard analysis.

B. IMPACT OF THE CENTER ON THE INFRASTRUCTURE OF SCIENCE AND ENGINEERING

1. Education Programs

Post-doctorial fellow, graduate and undergraduate research

Strengths

SCEC recognizes responsibility for educating individuals who will assume roles in earthquake research and risk reduction activities. SCEC provides research and education opportunities for post-doctoral fellows and graduate and undergraduate students. Education opportunities vary among participating institutions. According to the NSF Office of Integrative Activities as of October 23, 2000 center personnel numbered 262 persons. This includes 45 post-doctorial fellows, 46 graduate students, and 18 undergraduate students. According to the center, "work by students and junior staff are at the heart of most research sponsored by SCEC, and most investigator support goes to young scientists." Data provided to the site review team for the distribution of 1999 funding indicates that students received 35 percent of the center's funds, post-doctorial fellows 17 percent and research faculty (described as primarily young scientists) received 24 percent. The remaining 24 percent of 1999 funding supported technical staff and senior personnel associated with the center.

Recommendations

SCEC research results are integrated into undergraduate and graduate courses by responsible faculty without formal involvement of the center. One institution, USC, described an undergraduate survey course on earthquakes that benefited immediately from new center-generated knowledge. Increased emphasis is needed to facilitate the rapid integration of SCEC knowledge into university-based graduate and undergraduate education. University students nationwide would benefit from this effort. The panel recommends that SCEC use its position as the only earthquake science center in the United States to develop educational materials and make them available for university graduate and undergraduate courses. SCEC also should provide opportunities for undergraduate and graduate students to learn from center participants through summer programs, internships and student involvement in all center meetings. Southern California is a natural laboratory for visiting students to link geographic features with earthquake science. Moreover, providing materials for use in graduate and undergraduate courses at universities nationwide is a potential service to education as well as an excellent way to interest and recruit students from universities not participating in SCEC.

Students and researchers can gain a useful perspective on the use of earth science knowledge by participating in forums for engineering professionals and researchers. Collaboration with the NSF-sponsored earthquake engineering research centers can offer these opportunities.

Science and Earthquake preparedness education for K-12 students

Strengths

SCEC1 participated in revising and writing materials for K-12 educational use. SCEC helped revise *Tremor Troops* and *Seismic Sleuths* curricula. A middle school education module, *Whole Earth*, is being developed and will link to SCEC data. These materials provide an integrated and progressive, science based curricula available to all teachers nationwide. Regional Seismicity and Geodesy Web education modules were prepared for high school and undergraduate teachers using the SCEC data center and SCIGN network. SCEC also formed the "Developing Earth-Science Curricula Online" group involving educational product developers and classroom teachers to assess the content of web-based educational tools.

Recommendations

If SCEC2 elects to give K-12 curricula development and dissemination priority, it should develop the means to actively promote the use of its products by field-deployed courses and partnerships with existing teacher training institutions such as California State University System.

Informal Education

SCEC1 developed informal education tools such as the Wallace Creek interpretive trail, museum exhibits, Electronic Encyclopedia of Earthquakes, and other materials.

2. Involvement of Women and Minorities in Science

Strengths

NSF recognizes the societal importance of increasing the involvement of under-represented groups in science. The Science and Technology Center program calls for centers to exercise leadership in this area. The Golden, Menlo Park, and Pasadena offices of the U.S. Geological Survey have joined SCEC2 as core institutions. Several outstanding women and minority scientists at the U.S. Geological Survey offices are listed as participants in the proposal and will enhance involvement and visibility of under-represented groups in earthquake research in southern California.

Weaknesses

SCEC1 was encouraged by its Advisory Board and by the site review panel in 1996 to make a concerted effort to increase the participation of women on its Board of Directors and among working group leaders. Involvement of few women and minority scientists in SCEC2's leadership positions and science program remains a weakness. There are no women or minorities on the proposed SCEC2 administration at USC. Except for the Pasadena Office of the U.S. Geological Survey, there are no women or minorities serving as coordinators for core institutions and only about 12% of the investigators listed from both core and participating institutions are women. Only 7 women out of 174 scientists are at the core academic institutions that would receive the bulk of research funds. Several reviewers of the SCEC2 proposal identified the low participation of women and minorities as a serious problem. This is due in part to the low percentage of women and minority scientists in the earth sciences, especially in senior faculty positions. Nevertheless, it appears that SCEC2 could do more to recruit scientists of under-represented groups and to involve them in career-enhancing roles.

Recommendations

The panel recommends SCEC2 emphasize recruiting women and minority researchers and students in its programs and at participating institutions. The panel also recommends that SCEC2 consult with experts from its participating campuses to better understand the root causes of under representation in science and to adopt strategies to change participation in SCEC-funded activities. SCEC2 should work to assure that the post-doctoral fellows/visitor program attracts woman and minority researchers. The Principal Investigator or administrators of SCEC2 are called upon to show leadership and creativity in involving more scientists of under-represented groups in its research program.

3. Creation of Unique Facilities/Resources for Research Community's Use

SCEC1 facilities

In the past ten years SCEC1 devoted a significant portion of its budget to creating data centers in support of its research missions. The data centers have now been in operation for a few years. These are:

Seismology

1. Southern California Earthquake Data Center:
    - a) Event and phase data
    - b) Seismic time series for all triggered events
    - c) Continuous 20 sample per second data
    - d) Waveform dataset for significant southern California events
    - e) Selected Synthetic Aperture Radar images
    - f) Los Angeles Region Seismic Experiments time series
    - g) SCEC 3-D velocity model
    - h) Campaign GPS data

2. Strong Motion Data Base

A web-based database system that contains all the accelerograms recorded within California. The database is quite innovative in the strong motion world. It shares many common features with the functionalities of the IRIS database for weak motions.

3. Portable Broadband Instrumentation Center

A pool of broadband instruments is available for SCEC researchers to use at short notice.

Geodesy

Data from all the JPL/UCSD/USGS and SCEC fixed GPS stations are archived at the Scripps Orbit and Permanent Array Center (SOPAC). RINEX data (rather than the raw data) become available as soon as they arrive from the station site. Daily coordinate, periodic velocity solutions and plots of resulting positions or position differences are also available promptly.

A strength of the SCEC1 facility program is that within the past ten years, the basic facilities needed for the ambitious research program are nearly completed. The seismic data center went through a transition from a 1980's mini-computer era data center to a modern relational database management system. The establishment of the GPS data archive, for both mobile and fixed GPS stations, is streamlined. In particular the archiving of the GPS campaign (mobile) data breaks the tradition of PI ownership of such data. The mobile broadband instrumentation center, although it duplicates somewhat the function of IRIS/PASSCAL center, could allow more rapid response to regional earthquakes. At the end of the STC phase there is no major weakness of the SCEC facilities.

SCEC2 facilities

In SCEC2, SCEDC, SOPAC and SMDB described above will be the main facilities to be maintained. The SCEC2 headquarters is scheduled for renovation and thus the research space will be improved. Additional new facilities to support geological research will be added.

1. *Renovated Headquarters*. USC has set forth a plan, beginning in two months and will finish in two years a major renovation of the building in which SCEC is located. SCEC will benefit from augmented research and administrative office spaces as well as media center and conference rooms that enhance the functions of SCEC.
2. *Hardware for field investigations.* The purchase of a backhoe and shoring is planned. By owning these hardware items and hiring a technical person the cost of trenching is expected to decrease.
3. *GIS Center for archiving geologic database*. Hardware, software, and technical support will provide support to a host of SCEC activities.

A major innovation in SCEC2 is the incorporation of Information Technology to support the "Community Model" concept. Through commonly accessible models researchers will be able to cooperate across the SCEC (and perhaps also external) communities. This can be considered a facility as it will involve hardware, software and staff. Although a budget is included in this proposal to "nucleate" its implementation, it is recognized that a full-fledged implementation is beyond the scope of the SCEC2 budget. USC is looking to obtain separate NSF IT funding for it.

The strength of the facilities portion of the SCEC2 proposal is that most of the needs are already satisfied. The new facilities to be added are relatively small in scale compared to the existing ones. The GIS Center, in particular, will enable the SCEC2 researchers to flexibly utilize the modern digital terrain data (DEM), the Digital Earth data archive as well as spatial data acquired by SCEC itself. The ITR initiative potentially will provide the key vehicle through which the SCEC community can become a truly distributed science center.

One potential weakness is the financial support for SCIGN. Currently several organizations are behind the installation and maintenance of the network. The continued support on the part of some partners is not assured. Do new resources have to be sought in the future? Also the request of funds for the ITR initiative in this proposal is fairly small, although the impact could be quite significant. A separate proposal to the NSF ITR program is planned; how effective would SCEC be without the additional funds? The request for a backhoe is perhaps reasonable, but the lack of a utilization plan leads to the following questions: Is a capital investment such as this cost effective? How much will it be used? Would it be more economical to rent? Could it be effectively maintained? Should it be shared among other projects? Would SCEC also have to purchase a truck to transport the backhoe to sites across southern California?

Recommendations

The success of SCEC2 research will depend on the SCEC2 facilities. The support for SCN seems to be secure, but for SCIGN there is an element of uncertainty. Long-term support for such networks is crucial. Every effort must be made to secure such support, from the State and elsewhere.

4. Linkages to Other Academic Institutions and to Non-academic Sectors

The proposed extension of the Southern California Earthquake Center will group as many as forty universities and institutions to focus on research leading to a physics-based understanding of earthquake phenomena in the Southern California region. Following the leadership at the University of Southern California, core institutions will include major academic programs in earthquake science within southern California as well as respected academic programs on the east coast at MIT, Harvard University and Columbia University.

Membership as a SCEC participating institution is, and will be, inclusive of the entire research community since individuals from any institution are welcome to submit research proposals. Integral collaboration with the USGS offices in Pasadena, Menlo Park and Golden provides an excellent blend of theoreticians, modelers and application-focused scientists.

SCEC will enjoy a position of profound influence in southern California. By speaking authoritatively on issues of earthquake science and risk it will influence decision makers considering earthquake safety issues. As presented in the proposal, SCEC clearly recognizes its responsibility as an authoritative body. The panel commends SCEC for the statement in its mission to "...communicate this understanding to engineers, emergency managers, government officials, and the general public."

Strengths

SCEC1 pursued an admirable education and outreach program, especially during its last five years. Entrepreneurial leadership by the outreach director took advantage of opportunities in a number of areas and had developed useful products. Work with the media and efforts to develop educational materials and to provide information to the engineering community are particularly notable. The SCEC2 commitment to build on this record by working closely with the USGS on outreach and communications is an important enhancement for the center. The panel concurs with the statement paraphrased from the SCEC2 proposal that SCEC's most enduring accomplishment may be the demonstration that collaboration is the best way for communicating with others and recommends that SCEC work closely with other organizations to develop and implement this element of its program.

The panel also endorses SCEC's intention to evaluate and assess the effectiveness of its education and outreach products and believes that understanding the outcomes of its work, as contrasted with outputs, is essential to strategic management of the center and its limited resources. The panel believes SCEC2 must implement these evaluation and assessment plans.

The SCEC2 commitment to Communications, Education and Outreach should be viewed as a necessary prerequisite to funding the center. The proposal budget allocates 10 percent of center funds, or $450,000, to CEO programs, and two full time center positions—an assistant director for outreach and an outreach specialist. This level of commitment should be a minimum amount given the wide range of efforts needed to encourage use of the results of SCEC in science and society. The insights into earthquake processes are made more valuable through the CEO program.

Weaknesses

There is more to do than can be done. The annual commitment of $450,000 is limited in the face of the breadth of potential CEO activities. Unfortunately, outreach efforts in the region are not well coordinated and several organizations, including—but not limited to—the USGS, FEMA, state of California, local governments, Red Cross participate. Occasionally the information given is inconsistent, even conflicting. Although SCEC cannot control other organizations, it can, by working with them, encourage high standards of science in their statements.

Recommendations

The panel recommends developing specific objectives of its communications, education and outreach efforts by identifying the changed outcomes it seeks to accomplish and the strategy and resources needed to achieve them. The CEO program should be founded on SCEP expertise and linked directly to research results. The panel believes the SCEC leadership should work with southern California partners to decide which audience SCEC should address and the change it seeks to accomplish. A strategy for achieving the changes desired should be prepared using communications experts from commercial advertising, sociology and other disciplines. The CEO Plan would be equivalent in detail and stature to the Science Plan and would be completed in collaboration with the other organizations that undertake similar communications, education and outreach efforts in the region. The Panel cautions that because there is so much that can be done in this field, it is best to focus personnel and financial resources on strategic efforts rather than follow a pattern of doing a little in each area or simply responding to opportunities and succumbing to "mission creep."

Whereas the number of former, present and potential SCEC investigators is a true testament of the Center's ability to attract a great deal of research talent, one fear is that the large number of researchers will result in unwieldy management. Furthermore, because numerous research projects will be funded at a relatively low level, the allegiance of a single investigator may be poor and the presence of the center at core institutions other than USC may be weak. To alleviate these risks, it is recommended that fewer projects be funded at greater funding levels to those researchers who have proven to be effective in producing research results of value to the center.

Though some initial efforts have been made to link with the three NSF-funded earthquake engineering research centers, development of collaborative ties must continue. The proposed joint-activities with the PEER Center on development of risk management and performance-based engineering methods are a good start, however further activities with MCEER and the MAE Center should be pursued.

5. Leadership in the Research Community

As a unique center in the United States for coordinated studies of earthquake phenomena, SCEC has attained high visibility as a center of expertise in earthquake-related sciences. Through its research, outreach and educational programs, the center has established itself as the highest authority for seismic characterization of the Southern California region. With the proposed extension of the center for an additional five years, SCEC should continue to maintain this stature and visibility.

One of the challenges of the center will be for it to extend its leadership beyond southern California to other regions of the country and internationally. Its participation in the APEC Cooperation for Earthquake Simulation (ACES) is a good start in this direction. Further action should be taken to collaborate with earthquake centers in other parts of the world including Latin America and Europe.

C. Impact of the Center Mode of Support

Degree and kind of interdisciplinary and inter-organizational collaboration/ Degree and kinds of contributions beyond a collection of individual projects

Strengths

The proposed SCEC research plan will integrate research on four focus areas (structural representation, fault systems, earthquake physics and seismic hazard analysis) towards a common goal to develop a physics-based understanding of earthquake phenomena across the active-fault system of the southern California region. One strength of the proposed research plan is that funding allocations will be made through these four focus areas rather than through individual disciplines, as an attempt towards ensuring that interdisciplinary research will take place.

The center management is sincere with regard to ensuring that each focus area will indeed be cross or interdisciplinary rather than simply an assortment of mono-disciplinary projects that are coordinated. It is anticipated that teams of experts in geology, geodetics, seismology, geophysics, rock mechanics and information technology will solve common research problems in each focus area.

Weaknesses

One weakness of the proposal is that little definition of the research plan is given. Instead a general framework is described for how the research shall be integrated. Therefore, it is difficult to judge the degree and kind of interdisciplinary collaboration that will take place under each focus area. Much of the research plan is expected to unfold through an iterative process of issuing a request for and review of mini-proposals from the research community of the Center. Thus, at this time, specific research projects for any of the four focus areas have yet to be identified. Interdisciplinary participation in any of the focus areas can only be surmised. Integration among the four focus areas also is unclear.

Despite impressive presentations on each focus area by younger faculty, nearly no plans for each research program have yet to be made. This is felt to be a major shortcoming of the center proposal. During the site review, a few general milestones were mentioned for each focus area, yet no plans were given as to how these milestones would be achieved.

Whereas an open solicitation of the research community of the center is good for generation of intellectual ideas, a more solid, proactive program structure is advised. Moreover, rather than awarding projects in an annual incremental fashion as proposed, a phased sequence of multi-year projects is recommended to avoid projects from running past their anticipated completion dates. Reviews and approvals of research projects will still need to be made on an annual basis to avoid complacent attitudes among continuing investigators. However, a multi-year planning focus is necessary for directing the center towards meeting its objectives and goals.

The role of the disciplinary committees is difficult to comprehend. Segregation by discipline appears to be counter to the center's philosophy to be interdisciplinary. There is a plausible threat that investigators' interests may gravitate towards their traditional discipline-based roots if allowed to group within the structure of the discipline committees. The center management must take care that research leadership is provided through the focus areas and not through each discipline. This can be accomplished by maintaining funding lines, and thus accountability, through the research focus areas rather than the discipline committees.

Inter-organizational collaboration on research has a good potential to occur with the multi-institutional structure set by the Board of Directors. However, it should not be taken for granted. Often individual research groups tend to work by themselves without spanning across institutional lines. Care should be taken in management that investigators from different institutions are matched to solve common research problems.

Recommendations

Without a specific research plan showing what projects will be done at what institutions, detailed comments on inter-organizational collaboration must be deferred.

D. UTILITY OR RELEVANCE OF THE RESEARCH

1. Creation of Unique Research Theme and Environment within the Community

SCEC2 will continue the theme of SCEC1 as a unifying scientific organization for earthquake studies and outreach in southern California. SCEC1 has proven to be valuable not only for the scientific community but for the wider community as well. Outreach efforts to city, county, and state government bodies appears to be paying off in southern California as SCEC institutions coordinate their earthquake response efforts. The committee heard testimony from partnership organizations that seem to have been influential in raising state funds for seismic network expansion, for example.

Because southern California is a natural earthquake laboratory, SCEC2 should continue to serve as the premier earthquake science center. Although regional in scope, SCEC2's unique access to major facilities and active seismogenic structures really make it a national and international center of excellence for interdisciplinary studies in the earth sciences.

2. Impact of research contributions on the research community

Research conducted by SCEC1 scientists has had a major impact on the earthquake science community. For example, comparison of the results of GPS and paleoseismology studies has led to the observation that fault slip rates may vary during the earthquake cycle even at plate boundaries. Although originally initiated in San Francisco Bay region, modeling of stress transfer between faults matured in southern California following the 1992 Lander's earthquake. Also, development of the "cascading earthquake" model represents a major advance in the field of earthquake hazard assessment.

Some of the research results mentioned above were made possible by SCEC1's support of several data centers and instrumentation networks, as well as the high-quality and easily accessible data sets and models managed by SCEC1. The center's management of databases and open data policy has proved a highly effective way to share resources and to promote collaboration. SCEC2 will continue to manage Web-accessible databases and models for southern California that will further facilitate research by earthquake scientists, both affiliated and not affiliated with the center.

SCEC2 promises to develop new methodologies for integrating various types of data and models, predicting earthquake behavior, and modeling rupture dynamics, wave propagation, and stress transfer between faults. Advances in these areas would benefit the research community as a whole. Perhaps most importantly, SCEC1 has demonstrated that earth scientists in different disciplines can come together to work on a common problem and that interdisciplinary research can lead to significant advances in understanding earthquake behavior.

Recommendations

Given that a considerable portion of the national funding for earthquake research would be invested in SCEC2, the center has a responsibility to develop methodologies that will be applicable in other regions and to export the methodologies to the national and international communities through workshops as well as through publications. It would also benefit the research community in other regions to see how SCEC2 scientists have worked together to understand and reduce earthquake hazards in southern California. Due to the earthquake risk in southern California, back-ups of databases, models, and computer codes should be stored at a SCEC2 core institution in another part of the country.

3. Quality and Quantity of Knowledge/technology Transfer to Non-academic Sectors

Achieving the element of SCEC mission statement addressing "To transfer this understanding to other communities in Southern California and elsewhere by communication with scientists, engineers, emergency managers, and government officials, and through education of the general public." is admirable, but very broad. Fundamental to effective knowledge transfer is the development of consensus models and consistent scientific judgments for public policy and use in engineering. SCEC1 outreach to the engineering and government policy sectors deserves additional emphasis to improve the utility of its results. The strategic CEO plan should address this issue.

Outreach to the engineering community is vital to facilitating the use of SCEC knowledge. The panel recommends SCEC enter into formal agreements and joint projects with the NSF-funded MCEER, MAE and PEER earthquake engineering centers. These relationships should enable inter disciplinary discussions on science plans and mutually useful products. It is crucial that discussions address SCEC consideration of new techniques for describing the earthquake hazard for engineering use.

Recommendations

The panel recommends that SCEC-funded scientists should be encouraged to participate in earthquake engineering meetings, symposia and workshops. Candidate organizations include the Structural Engineering Association of California's Seismology Committee, Earthquake Engineering Research Institute, Association of Engineering Geologists and similar organizations that support engineers and geologists engaged in analysis of earthquake risk and design in the private and government sectors.

One potential application of SCEC knowledge occurs when someone predicts the time, magnitude and location of an earthquake in California. California law establishes the California Earthquake Prediction Evaluation Council (CEPEC) as the body to advise the Governor on the scientific basis of the prediction. This advice is part of a process that enables informed decision making by the governor and local governments and triggers important immunity provisions of state law regarding the resulting decisions. SCEC should seek formal representation by a center official (the director or deputy director) on this panel.

E. INSTITUTIONAL SUPPORT AND CENTER MANAGEMENT

1. Financial and in-kind support beyond NSF

Substantial leveraging of NSF funds is proposed with augmented support from USGS equal to one third-to-one half of the NSF budget. In addition, cost sharing by individual core institutions is significant at over $23 million estimated over five years from university hard funds, faculty release time, USC facilities for the central administration, and USGS salaries. Thus, the total budget for SCEC should be approximately three times the NSF budget. Moreover, efforts are underway to acquire support from the state of California and industry. This excellent leveraging is a true strength of the proposed center.

2. Stability and creativity of Center management mechanisms

Because of the size and complexity of the proposed center, an effective and simple management strategy is essential. Some creative thought has been given to an organizational structure that is responsive to the needs of a multi-institutional and inter-disciplinary center, yet a clear and concise management plan is lacking. For example, an organizational chart is yet to be developed to delineate the respective roles of the central administrative staff and the relationships between the Board of Directors, the Planning Committee, and the Advisory Council. The management plan must be developed further.

The matrix approach of research management, assigning accountability of investigators to both programs and disciplines, has been tried in other centers with varying degrees of success. This dual management approach will require considerable oversight from the central administration so that the desired interdisciplinary focus will be achieved without a dominating influence of any one discipline.

F. ANALYSIS OF PROPOSED BUDGET AND BUDGET JUSTIFICATION

It is the understanding of the panel that SCEC2 will largely function like SCEC1 in that funds will be dispersed to the 14 Core and 26 participating institutions through oversight of scientific management. Some funds go towards nominal support of scientific infrastructure and other funds to scientific projects. SCEC2 management appears to have determined a balanced way of dispersing funds between these major categories.

Although the combined proposed budget to the NSF and the U.S. Geological Survey is relatively large, ~$4.5M per year for 5 years, clearly these funds must be spread over the 40 (or more) institutions that wish to participate in SCEC2. Some participating institutions, for example, are listed at $20K per year in later years representing only very modest scientific support. By this criterion, SCEC2 could be a very good value for the money, if scientific and outreach goals are actually accomplished. Based on the experience of SCEC1, it is likely that this modest support will be leveraged by investigators at their home institutions through in-kind institutional support (e.g., graduate students, post-docs) and through additional grant funds won from national science programs. Thus, SCEC2 brings a focus to research on earthquake science in southern California by only being a source of modest funds for investigators.

Support from Core institutions looks to be substantial and real, in contrast to comments made by one outside reviewer. Support from the home institution (USC) is very substantial and involves additional monies for building renovation. USC is also continuing its practice of not charging overhead on subcontracts to the other institutions of SCEC2. This clearly adds value to the proposed financial management of the center.

Nevertheless, several outside reviewers were critical of funding SCEC2. Several reviewers were concerned that funding SCEC2 would take away significant resources from the rest of the earthquake science community. The perception seemed to be that most SCEC1 funding came from an NSF budget different from the Geosciences Directorate and that the new center would take a disproportionate amount of the small grant funds. This issue seems best addressed by the NSF and the U.S. Geological Survey in their own internal planning and communication with the community at large. It would be useful for these agencies to brief the community on the complexities of their general budgeting process and allocations made for earthquake science.

Another reviewer stated that there was enough funding for SCEC2 to attack scientific problems but that the CEO program is under funded. It was clear from the SCEC2 site visit that many more dollars could be devoted to addressing the major scientific issues posed in the proposal. Thus, the problem of budget becomes one of balance that will be affected by the contingencies of the funding agencies in the amount of support that they may offer to SCEC2. This balance will have to be determined through careful oversight by the SCEC2 management.

One obvious failing of SCEC1 was to build a base support of funding from sources different from the NSF and USGS. SCEC1 did succeed in garnering support for specific projects in Education and Outreach and early projects in earthquake engineering, yet primary support came from the original two funding agencies. One of the goals of the STC program at NSF was to have centers become independently funded after 11 years. There seems to be potential for industry and state funding of SCEC2. Because of the emphasis on 3D structure and fault systems in the Los Angeles Basin area, one potential source of support could be through an oil industry consortium. The visiting committee heard testimony from several civic and state groups that SCEC1 provided much needed information and leadership concerning earthquake hazards in southern California. It would be useful for this moral support to be translated into some level of financial support. In both examples, it would probably take one or two individuals to assume leadership in these quests for support. Perhaps the development office at USC could be approached by the SCEC2 leadership with these projects in mind.

In summary, the size and distribution of the budget appears to be justified based on the large scope of scientific and outreach work proposed. The budget will be leveraged by institutional support and by other support garnered by SCEC2 investigators. Support of SCEC2 must be placed in a context that includes a balanced assessment of national and funding agency needs. The management of SCEC2 should be strongly encouraged to seek additional funding from other sources.

G. RECOMMENDATION

1. Summary of Strengths and Weaknesses

This proposal builds on the successes and strengths of SCEC1. SCEC1 was very successful in focusing the efforts of a large number of researchers in southern California and nationwide on the problem of earthquake hazards in southern California. This was a unique accomplishment in the earth sciences. SCEC2 is based on an admirable desire to make significant inroads on the tough scientific problem of earthquake occurrence. The intellectual merit of this problem is unquestioned. It is very likely that researchers at SCEC2, if funded, will make significant progress in addressing relevant scientific questions.

Nevertheless, there are significant weaknesses to the proposal that must be addressed before funding can be committed. The science plan is not well defined. SCEC2, as proposed, has many general research goals but few specific milestones or research products. The committee recommends that:

SCEC2 management organize the focus group structure to determine specific research milestones and products for each interdisciplinary focus.

Furthermore, we recommend that:

SCEC2 management prioritize these milestones and products on the basis of probable scientific contribution and success toward the goals of SCEC2.

These recommended clarifications by SCEC2 management are necessary since the level of funding of the new center is largely unknown. We believe this would be very helpful to the funding agencies in prioritizing their plans and it would be helpful to the earth sciences community at large for understanding SCEC2's research contribution.

2. Funding Recommendation: Support

USGS SCIENCE Activities in Support of SCEC2 GOALS—

An Informal Report

by
Mary Lou Zoback, Chief Scientist;
Ruth Harris and Andy Michael
USGS Earthquake Hazards Team, Menlo Park, CA
and
Lucy Jones
USGS Earthquake Hazard Team, Pasadena, CA

Introduction

SCEC2's stated science goal is a "comprehensive and predictive understanding of earthquake behaviors". This goal is closely aligned with and directly pertains to the USGS Earthquake Hazard Program's goals:

a) Improve earthquake hazard identification and risk assessment methods and their use
b) Maintain and improve comprehensive earthquake monitoring in the United States with focus on "real-time" systems in urban areas;
c) Improve the understanding of earthquakes occurrence and their effects and consequences.

The purpose of this informal report is to summarize USGS research activities and projects in support of SCEC2 goals and to highlight two major opportunities with the USGS to broaden the scope and impact of SCEC2 science. We expect that USGS scientists will be participating in all four major focus areas in SCEC2: structural representation, fault dynamics, fault system kinematics, and seismic hazard analysis; as well as in the engineering interface and the Communication, Education and Outreach program.

Key USGS Contributions to SCEC2 Science Goals

USGS participation provides scientific leadership in several areas critical to the success of SCEC2 goals:

- seismic hazard analysis
- geodetic monitoring and interpretation
- earthquake physics, an area of highlighted emphasis in SCEC2.

In the area of seismic hazard analysis, USGS participation provides a critical link between the joint USGS/SCEC Regional Earthquake Likelihood Models project (RELM) and the USGS National Seismic Hazards Map project in Golden, Colorado, assuring that the methodology innovations developed by RELM will directly impact the federally mandated maps, not just for southern California, but throughout the United States. The

USGS will continue to play a key role in the leadership and real-time utilization of data from the SCIGN network.

The USGS brings considerable strength to SCEC2's earthquake physics science objectives through:

- world class rock mechanics labs
- in-situ measurement and analysis capabilities (heat flow, stress, permeability, and other physical properties)
- theoretical rupture dynamics studies
- fault interaction/stress transfer studies.

Continuing USGS/SCEC collaborative projects and opportunities for expanded collaborations in support of SCEC2 goals based on research activities and projects of the USGS Earthquake Hazards Team are summarized in the second half of this report.

New Opportunities

Two on-going major USGS research projects provide tremendous opportunities to broaden the scientific scope and impact of SCEC2: 1) a real-time earthquake physics laboratory on the San Andreas fault at Parkfield, California; and 2) quantification of earthquake hazards in the offshore region of southern California.

Building on more than fifteen years of surface fault zone monitoring, we are expanding the Parkfield "earthquake prediction" experiment into a real-time, in-situ earthquake physics lab on the San Andreas fault zone. EarthScope's San Andreas Fault Observatory at Depth, SAFOD, project (co-PIs Steve Hickman and Bill Ellsworth, USGS, and Mark Zoback, Stanford) which will directly sample the physical and chemical processes controlling earthquake generation at 4 km depth is obviously be a key element of this effort. The real-time natural laboratory will integrate in-situ determination of physical/fluid properties within the fault volume (both at the surface and at depth) with very high-resolution seismic imaging of fault zone through earthquakes and active sources. The San Andreas fault zone at Parkfield is already the densest instrumented active fault zone in the world, the addition of the SAFOD experiment will add critical information in the third dimension. The goals of our earthquake physics lab at Parkfield are threefold:

- Observe the build-up and release of stresses on the San Andreas fault through multiple earthquake cycles
- Build and test physics-based models of the earthquake cycle to determine the feasibility of short-term prediction
- Measure near-fault shaking during earthquake rupture to learn how to predict amplification of shaking due to dynamics of rupture and different soil types.

Although funding for EarthScope is still pending, a 2-km-deep vertical pilot hole is planned at Parkfield in the late spring of 2002 (pilot hole will be drilled at the same site planned for the main SAFOD hole). This hole, which will be developed as a collaborative effort between the International Continental Drilling Program, NSF, and the USGS, will guide subsequent SAFOD scientific investigations. This pilot hole will provide key physical property information in the fault volume and provide an opportunity for dense borehole instrumentation including a seismic "antenna" which will facilitate precise location of earthquake hypocenters, and provide detailed velocity control for the fault zone. It will also allow testing of prototype instrumentation Monitor time-dependant changes in physical properties and the mechanical state of the crust adjacent to the fault zone.

The second key opportunity for greatly expanded USGS/SCEC2 collaboration is in the area of quantifying earthquake hazards in the offshore and coastal regions of southern California. This collaborative effort would include characterizing earthquake source zones in the offshore region, linking onshore/offshore deformation and deformation history, and quantifying earthquake effects. It will involve ongoing USGS research in both the Earthquake Hazards (EHZ) and Coastal and Marine Geology CMG teams as well as extensive CMG data collection efforts. The SCEC2 proposal discusses working with the NSF MARGINS program on offshore earthquake hazard problems. We believe the USGS and the MARGINS group have many complementary interests and capabilities and feel the time is ripe to develop a SCEC2 offshore research strategy building on the strengths of the USGS, SCEC2, and MARGINS communities.

USGS CMG team members are currently analyzing several thousand km of high-resolution seismic-reflection and side-scan and multibeam sonar data they have collected from the Mexican border to Santa Monica Basin (and which is to be extended to Santa Barbara Basin during the 2001 field season). Figures showing CMG seismic data coverage and sample sections are included in Normark et al., 1999, Cruise Report for 01-99-SC: Southern California Earthquake Hazards Project, USGS Open-File Report 99-560, which can be viewed online at http://geopubs.wr.usgs.gov/open-file/of99-560/.

As a result of the history of offshore lease sales in southern California, a large amount of industry seismic-reflection data may become publicly available over the next 5 years. These data become available for copying and research used 25 years after they were obtained. Both USGS and SCEC researchers already have access to some of these data. Ultimately the integration of these data with USGS CMG high-resolution marine seismic data and the LARSE seismic lines should help connect the structures imaged in the high-resolution shallow seismic data with deeper structures at seismogenic depths and to connect onshore and offshore structures. This data presents a unique opportunity because environmental regulations now make it virtually impossible to operate the large airgun arrays necessary to image deep structures.

Once potentially seismogenic structures have been imaged offshore and possibly linked to onshore structures, it will be critical to determine the deformation history of these features and the timing of previous earthquakes. The FOQUS-LA project (described below) is developing a Quaternary sequence stratigraphy model for the LA basin and adjacent offshore region. Dating deformation features stratigraphically can help constrain deformation rates, but 50 to 100 m deep cores for radiocarbon dating are needed for calibration and precise timing of past events. This could be an ideal collaborative effort with the MARGINS group since they already have this coring capability.

Research efforts on earthquake effects estimation related to offshore or coastal earthquakes needs to emphasize tsunami generation and deep crustal modeling in order to predict seismic wave focussing and amplification onshore from offshore earthquakes. One of the critical areas of major shaking and ground failure hazards in southern California are ports and harbor regions. These regions have been poorly characterized to date. Researchers in the USGS EHZ team have been successfully mapping liquefaction and shaking potential by integrating dense cone penetrometer measurements with geology of near-surface deposits. This approach could be very effective for hazard definition in the port and harbor areas.

Key USGS Personnel:
Marine seismic work—*Bill Normark, CMG; Mike Field, CMG; Stephanie Ross, CMG*
LARSE data—*Gary Fuis, EHZ; Janice Murphy, EHZ*
Tsunamis hazards--*Eric Geist, CMG; Homa Lee, CMG*
Liquefaction hazards—*John Tinsley, EHZ; Tom Holzer, EHZ*

USGS PROJECT WORK--CONTINUING USGS/SCEC COLLABORATIVE EFFORTS AND OPPORTUNTIES FOR EXPANDED COLLABORATION

The focus below is on continuing and potential new collaborative opportunities involving personnel and on-going projects of the USGS Earthquake Hazards Team (EHZ) headquartered in Menlo Park, California. EHZ has 3 main offices: Menlo Park, Pasadena, and Seattle. All work in the EHZ team is carried out in one of 10 Megaprojects:

Project	*Project Chief*
Southern California Earthquake Project	Lucy Jones
Focus on QUaternary Stratigraphy of LA (FOQUS-LA)	Dan Ponti
Earthquake Effects	Jack Boatwright
Physics of Earthquakes	Steve Hickman
Earthquake Probabilities	Andy Michael
Crustal Deformation	Wayne Thatcher
San Francisco Bay Area Eq Hazards Project	David Schwartz
Northern CA Seismic Network	David Oppenheimer
National Strong Motion Program	Woody Savage
Pacific Northwest Eq Hazard Studies	Craig Weaver/Tom Brocher

Nearly all projects have existing or potential strong collaborations and contributions to SCEC2 goals. For example, all seismic networks in California (weak and strong motion, USGS, academic, and CDMG) have now been integrated in the CISN (CA Integrated Seismic Network). Our goal is one statewide earthquake catalog, redundancy and backup between northern and southern operational centers, and compatibility of all software—no small goal. Obviously this integration will be an important part of helping to achieve SCEC2 objectives. In addition, it is anticipated that the National Strong Motion Program will work actively with the engineering interface in SCEC2.

Pasadena Office (summary prepared by Lucy Jones)

All activities in the Pasadena office are within the Southern California Earthquake Megaproject, which also includes some geologists and crustal studies personnel in Menlo Park. Areas of strong interaction with SCEC are described below by tasks in the Southern California Earthquake Project.

I. Task 2: Southern California Integrated GPS Network

The USGS has been a core partner of the effort to develop the SCIGN network since its inception. The USGS has primary responsibility for real-time data collection and rapid post earthquake response. The USGS will provide earthquake response information from the network in the event of an earthquake, and also has a lead role in operating the network with responsibilities in maintenance of stations and downloading of data. USGS scientists chair the SCIGN Board and Executive Committee (Hudnut) and the analysis committee (King). We are leading research efforts analyzing the SCIGN data to infer secular velocities and fault slip rates. Problems in research areas of tectonics, earthquake sources, and fault mechanics will be addressed with a combination of data from SCIGN and other sources (such as SAR interferometry, Airborne Laser Swath Mapping, etc.), along with geophysical modeling.
with key personnel
Hudnut, King, Prescott, and Langbein

II. Task 6: the RELM project

RELM, a working group for the development of Regional Earthquake Likelihood Models, is the lead activity of the Southern California Earthquake Center (SCEC) in the area of Seismic Hazard Analysis, and is a significant focus of collaboration between SCEC and the USGS. The group presently involves more than 20 direct participants, and more than 70 individuals paying close attention (i.e., on the all@relm.org email list).

Previous working group efforts have demonstrated that we have not reached consensus on how to construct earthquake-forecast models. Therefore, the goals of RELM are: 1) to develop a variety of viable, geophysically based earthquake-forecast models for the region (a specification of where and how often all damaging earthquakes are likely to occur); 2) to test these models for consistency with existing geophysical data (e.g., historical seismicity); 3) to design and document conclusive tests with respect to future observations (establish stationary targets); and 4) to examine and compare the present hazard implications of each model. This effort will help define existing uncertainties in seismic hazard analysis, identify research topics needed to reduce these uncertainties, and identify which models are exportable to other regions where the options are fewer.

The USGS will be a major partner in this effort. Ned Field leads the RELM focus group for SCEC and USGS scientists are involved in several aspects of the project, including the catalog, velocity field, short-term probabilities, and JAVA PSHA code, hazard model and fault database development. The fault activity database (FAD) in particular is being based on the FAD developed in the USGS Southern California Earthquake Project over the last few years. Several of the modeling efforts also involve USGS participants, including the stress transfer modeling and the aftershock short-term rate variation modeling, some of these participants are described below in the Menlo office.
Key personnel
Field, Jones, Kendrick, and Hecker

RELM, through its USGS leadership, will their activities with the National Seismic Hazard Mapping effort in the USGS Golden office with key personnel
Frankel, Petersen, and Leyendecker?

III. Task 8 TriNet Site Characterization
In a cooperative effort with the Earthquake Effects MegaProject in Menlo we are proposing to prepare a site characterization database for strong motion and broadband stations in the Southern California Seismic Network. An in-depth knowledge of local site conditions and site effects is critical to understand fully the ground motions recorded at TriNet stations and to allow researchers and practitioners to fully exploit this valuable dataset. Also, the wealth of recorded TriNet data provides a unique opportunity to further investigate the physical processes associated with site response, including the nature of ground motion in sedimentary basins.

The effort will include: 1) adapting the TriNet station database to include geologic site characterizations for SCSN stations; 2) a preliminary geologic evaluation of all TriNet strong motion and broadband sites; collate esiting shear wave velocity profiles and other site information in southern CA, 4) comparison of site information with magnitude station corrections (site amplification factors). All this data will be prepared in a public, web-accessible database.
key personnel
Hough and Tinsley

Menlo Park Office (prepared by Ruth Harris and Mary Lou Zoback)

At least 5 of the Megaprojects in Menlo Park have goals that are very close to or complement those of SCEC2. Some of the activities in these projects and their key personnel are summarized below.

I) Physics of Earthquakes Megaproject

The megaproject gathers information about fault zone physical properties and conditions at the depths where earthquakes take place, and combines this information with observations of earthquakes and laboratory experimentation on natural and synthetic fault rocks to yield useful models of the processes that cause earthquakes.

This megaproject will assist and provide major leadership with the subject that is at the heart of SCEC2, earthquake physics, by collaborating with the Focus Group Earthquake Physics and the Disciplinary Activity Rock Mechanics. The Menlo Park group is the world's leader in earthquake physics and also has the extensive laboratory facilities to assist SCEC2 in its efforts in this arena.

Two specific activities within the megaproject closely relate to SCEC2 goals . The first is construction of a real-time and (eventually predictive?) model of an active fault zone taking advantage of a natural earthquake physics lab at Parkfield, CA by integrating: 15+ years of the densest surface fault monitoring network in the world, in-situ determination of physical and fluid properties at depth in the San Andreas fault volume, and, high resolution seismic imagery of the fault. (This natural laboratory experiment was described above under *New Opportunities*)
Key personnel: *Hickman, Ellsworth, Langbein, Roeloeff, and Zoback (at Stanford)*

A second project effort closely related to the earthquake physics goal is laboratory and theoretical determinations of the strength and frictional behavior of fault rocks at seismogenic conditions, the role of fluids and how these factors affect earthquake nucleation and propagation.
Key personnel: *Dieterich, Hickman, Lockner, Harris, Moore, Beeler, McGarr*

2) Probability of Earthquake Occurrence Megaproject

This megaproject starts with observations, constructs and tests models, then proceeds to use the information to construct probabilistic scenarios of earthquake occurrence. This megaproject also has a close tie to RELM in southern California and has close ties to SCEC2 Focus Groups Fault Systems, Earthquake Physics/ Rupture Dynamics, and Seismic Hazard Analysis.

Specific activities within the megaproject that closely relate to SCEC2 goals include
(1) Earthquake and fault interaction (a.k.a. "stress transfer") studies
Key personnel: *Simpson, Stein, Harris, Stuart, Pollitz, Parsons, Gomberg, Dieterich*
(2) Single and multiple fault spontaneous rupture earthquake scenarios
Key personnel: *Harris, Andrews*
(3) Evaluations of statistical models for earthquake occurrence
Key personnel: Ellsworth, Reasenberg, Stein, Dieterich

3) Earthquake Effects Megaproject

The megaproject's primary goal is to produce ground motion maps for scenario earthquakes using models that include our best understanding of earthquake rupture and wave propagation. The models include source, path, and site effects. The megaproject also collects seismic data using temporary and permanent arrays. These megaproject's goals tie very closely with those of the SCEC2 Focus Group Wave Propagation and the SCEC2 Implementation Interface, in addition to the_Disciplinary Activity Seismology. Although the megaproject is primarily concentrated on understanding earthquake effects in the San Francisco Bay area, many parts of the project have generic applications and could and should be transported to SCEC2 studies for southern California.

Specific activities within the megaproject closely related to SCEC2 goals include
a) Developing new equations to predict strong ground motion as a function of earthquake magnitude, distance, directivity, and site condtions.
Key personnel: *Boore, Boatwright, Andrews*
b) Quantifying how earthquake ruptures propagate vertically and horizontally along faults.
Key personnel: *Fletcher, Spudich*
c) Quantifying the effects of earth structure on wave propagation.
Key personnel: *Fletcher, Boatwright, Lindh, Spudich, Boore*

4) Crustal Deformation Megaproject

The megaproject measures and records aseismic motion of the earth's crust. The measurement of aseismic deformation includes determination of the plate motion rates that drive earthquakes in California, Oregon, Washington, and Alaska, of strain rates in interplate areas of the US, as well as the recording of small transient strain signals associated with fault motion that may be related to earthquake generation. Project efforts have close ties to the SCEC2 Disciplinary Activity Geodesy and the southern California SCIGN effort, which has involved continuous GPS measurements. In addition, the megaproject collects and integrates with physical models other types of deformation recordings including InSAR and strain meters.

Specific activities within the megaproject that closely relate to SCEC2 goals include estimating the variability of deformation rate with time between earthquakes and reconciling the measured aseismic deformation with the energy released in earthquakes.
Key personnel: *Prescott, Thatcher, Johnston, Langbein, Stein, Bawden, Pollitz*

5) Focus on QUaternary Stratigraphy of the Los Angeles Basin (FOQUS-LA) Megaproject

FOQUS is a large, interdisciplinary project with the goal of developing a geologic framework to better understand ground water sources and earthquake hazard issues in southern CA by developing a regional scale sequence stratigraphy model for the Quaternary of southern California. Specific earthquake hazard objectives include: 1) understanding how stratigraphy and sedimentological processes help control the distribution of seismic hazards and earthquake effects and 2) defining the seismic potential (including past rate of movement) of buried and exposed faults. Sediment coreholes will also be used to measure heat flow. There is significant funding for this project from several metropolitan water districts in the LA region.
Key personnel *Ponti, Tinsley, and Colin Williams; all EHZ; Brian Edwards, CMG*

SCEC Communication, Education and Outreach Program

October 2000 – January 2002

By Mark Benthien

SCEC has always viewed the transfer of its research results to other communities as an essential component of its mission. The SCEC1 Communication, Education and Outreach (CEO) program has established itself among SCEC's external communities as a valuable resource for Southern California, both for its products and for the expertise its CEO staff has developed in coordinating effective dialogue and cooperative projects among multiple communities. During the last year, the efforts in this direction have been evolving with the rest of SCEC as we transition to SCEC2. Plans for SCEC2 CEO have been developed through a series of discussions, presentations, and workshops with member of the SCEC Community and external partners. While much of the year has been devoted to the future, many programs have continued and are presented here, followed by plans for the remainder of SCEC1 during the transition to SCEC2.

SCEC CEO long term goals have been revised this year as the following:

- Promote earthquake understanding and general science literacy at all educational levels.
- Reduce economic losses and save lives by increasing earthquake awareness and improving hazard and risk assessments

During the last year, SCEC's CEO program has pursued four main objectives, originally outlined in the SCEC2 proposal:

- Objective 1: Build upon the intrinsic interest of students and the public in the natural environment
- Objective 2: Utilize the scientific and educational expertise of SCEC
- Objective 3: Expand access to earthquake information via the Internet and other media
- Objective 4: Foster a greater public understanding of earthquake risk

The following CEO activities this year have been accomplished:

Objective 1: Build upon the intrinsic interest of students and the public in the natural environment:

Wallace Creek Interpretive Trail. In partnership with The Bureau of Land Management (BLM), SCEC designed an interpretive trail along a particularly spectacular and accessible 2 km long stretch of the San Andreas Fault near Wallace Creek. Wallace Creek is located on the Carrizo Plain, a 3-4 hour drive north from Los Angeles. The trail opened in January 2001. The area is replete with the classic landforms produced by strike-slip faults: shutter ridges, sag ponds, simple offset stream channels, mole tracks and scarps. SCEC created the infrastructure and interpretive materials (durable signage, brochure content, and a website with additional information and directions to the trail). BLM has agreed to maintain the site and print the brochure into the foreseeable future. (www.scec.org/instanet/00news/news000913.html and www.scec.org/wallacecreek)

SCEC Museum Partnerships. SCEC has established a partnership with the Riverside County Children's Museum, CUREE-Caltech Woodframe Project (for which SCEC has managed the education and outreach activities), and UC Riverside to create an educational, family-oriented exhibit on earthquakes in their region. "ShakeZone," to be completed in fall 2001, will occupy fully half the space at "KidZone." The mission of the exhibit is to reach the local community, particularly elementary and secondary school children, with positive messages about studying the Earth and preparing for earthquakes. The exhibit will present information about science, engineering, safety and mitigation. A shake table, an interactive computer display, and wall displays will teach the visitors about the tools and techniques of earth scientists, engineers and emergency services personnel. (www.scec.org/instanet/00news/news000619.html)

2001 Summer Internship Program. To provide hands-on experiences in the earth sciences or science outreach, provide insights into career opportunities, and interest underrepresented undergraduate students in Earth science-related careers, SCEC has funded 72 students (including 39 women and 16 minority students) to work alongside 50 SCEC scientists over the past 7 years. For summer 2001, the program was not funded through SCEC due to budget constraints in the last year of NSF funding, however three undergraduate students participated in a modified program based on funding from research mentors. To begin the summer, the interns attended a Communication Workshop held jointly with interns from the Pacific Earthquake Engineering Research Center (PEER). Students participated in a two-part field trip led by Dr. James Dolan (USC) and Dr. Doug Yule (CSUN). Finally, students present posters at the SCEC annual meeting. (www.scec.org/internships)

Los Angeles High School Field Trip. On June 13th Tom Henyey and Bob de Groot led a field trip for thirty 9th grade students from Los Angeles High School. Richard Redman, their enthusiastic teacher provided his students with the basics of plate tectonics before taking the trip. Redman made contact with SCEC in April during a LAUSD earthquake education workshop at UCLA (see below). (www.scec.org/instanet/01news/news010702.html)

Earthquake Day at the California Science Center. SCEC CEO staff member Robert de Groot assisted with an earthquake education field trip at the California Science Center on January 18th. Students first visited The Earthquake Experience, a human size shake table with a video presentation. After being "shaken up" the students fanned out to learn about liquefaction, plate tectonics, the response of buildings to earthquakes and how to construct an earthquake survival kit. (www.scec.org/instanet/01news/news010205.html)

Objective 2: Utilize the scientific and educational expertise of SCEC

Seismic Sleuths Revision and Earthquakes: Seismic Sleuths video. NSF has funded SCEC to revise the AGU/FEMA *Seismic Sleuths* middle school earthquake curriculum to reflect advances in science and technology since the last update in 1995. The objectives are to promote and improve natural hazard education for students; to foster preparedness for natural hazards through empowerment and encouraging personal responsibility; to provide an updated and redesigned learning tool that can be easily integrated into a curriculum based on national standards; and to provide constant updates in science content, pedagogy, and resource information through an interactive website. Each unit has been streamlined and can stand alone in order to be used in a variety of environments. In addition, a television special (*Earthquakes: Seismic Sleuths*) based on the series has been created, made possible by funding from the California Earthquake Authority, the Institute for Business and Home Safety, and SCEC. The hour-long video was broadcast on "Assignment Discovery" in spring, 2001. The video can be used by teachers as an excellent advance organizer, or viewed by interested citizens who want to learn more about earthquakes, the destruction they can cause, the scientists and engineers who study them, and what they can do to prepare. (www.scec.org/instanet/00news/news000808.html and www.scec.org/instanet/01news/news010330.html)

Electronic Encyclopedia of Earthquakes. This collaborative project between SCEC, CUREE and IRIS will synthesize a large and varied amount of data and information and provide broad access via the Internet in the context of the NSF-funded Digital Library for Earth System Education (DLESE). The subject matter will feature Earth science and also include engineering, physics and mathematics. The collection is primarily aimed at supporting high-quality high school and undergraduate education by providing educators and students with the tools and resources for instruction and research. The wide field of knowledge to be eventually included within the scope of the encyclopedia (2,000 entries are planned) renders the long-range project ambitious, but feasible if one considers the qualifications and resources of the three partners in the project. In 2001 a $600,000 proposal from SCEC, CUREE, and IRIS was accepted by the National SMET Digital Library for multi-year funding to continue the development of the Encyclopedia. The framework for the Encyclopedia has been developed and the content collection process is continuing. (www.scec.org/ecube)

Online Education Modules. SCEC's two online education modules (*Seismicity* and *GPS*) were on display at the Annual Conference of the California Science Teachers Association (CSTA), held at the Convention Center in Sacramento on October 12 - 15. The theme for this year's conference was "Honor the Past. Imagine the Future." In keeping with this theme, both SCEC presentations demonstrated how our products combine the newly emerging power of the Internet with a more traditional hands-on approach to science education. (www.scec.org/instanet/00news/news001110.html)

The Real Meaning of Seismic Risk Symposia. The objective of this symposia series is to increase public awareness and understanding of urban seismic risk and related social and public policy issues. In 2000 SCEC conducted two "Earthquake Preparedness for Schools" symposia as part of this series, in partnership with Los Angeles City Emergency Planning Commission. About 75 educators attended the June symposium that featured presentations on earthquake awareness, preparedness and mitigation for K-12 teachers and school administrators. Over 200 educators attended the November symposium that followed the same format. The presentations have been recreated for SCEC InstaNET News as web pages, including video clips from the symposium. (www.scec.org/instanet/00news/feature001109.html)

LAUSD Earthquake Education Workshop. On April 18th SCEC sponsored a professional development seminar for middle and secondary educators of the Los Angeles Unified School District. This program was held at UCLA in conjunction with the Los Angeles Systemic Initiative, an organization that provides dynamic educator in-service programs. Keynote speaker Tom Henyey presented an update of the hot topics in earth science while skillfully weaving a valuable review of earthquake basics into his discussion. During the second half of the program John Marquis and Bob de Groot, SCEC CEO staff, gave presentations in two different breakout sessions. Marquis conducted an online tour of the SCEC website and other on-line earth science resources. In the other session, de Groot shared earthquake activities that were applications of several topics highlighted in Henyey's address. After the meeting Marquis and de Groot remained with the group to answer questions and be available for discussion. (www.scec.org/instanet/01news/news010419.html)

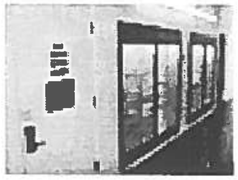
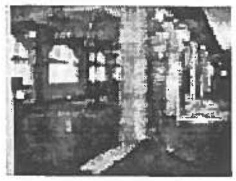
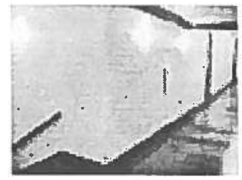
Objective 3: Expand access to earthquake information via the Internet and other media

SCEC Webservice and SCEC InstaNET News. SCEC's webservice (http://www.scec.org) presents the research of SCEC scientists, provides links to SCEC institutions, research facilities, and databases, and serves as a resource for earthquake information, educational products, and links to other earthquake organizations. Last year SCEC introduced the SCEC InstaNET News to provide a source of information in all matters relevant to the SCEC community: to disseminate news, announcements, earthquake information, and in-depth coverage of earthquake research, in a timely manner via the World Wide Web. Since its inception in March 2000, over 1300 people have subscribed to e-mailed news "bytes" which announce new articles. (http://www.scec.org/instanet)

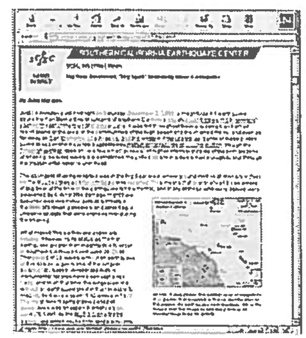
In addition to meeting and job announcements, news from SCEC partners, and other news, CEO staff produced articles detailing many of the CEO activities described in this report. Furthermore, CEO staff also produced many other pieces (see table 1).

Table 1. Sample *SCEC InstaNET* articles on other topics

SCEC Headquarters Remodeling. During summer 2001, The progress of the renovation and retrofit of the building which has housed the SCEC administration and outreach offices has been tracked on the InstaNET pages with pictures (www.scec.org/instanet/01news/feature070201.html)

Comparison of Northridge and Nisqually Earthquake. This article presents a comparison of the geological aspects of the two earthquakes, which account for most of the differences in resulting damage. (www.scec.org/instanet/01news/feature010313.html)



Recently published SCEC research papers. Abstracts and complete references for fifteen recently published papers based on research sponsored by SCEC are now available via SCEC InstaNET News. (www.scec.org/instanet/01news/center010803.html)

A Minor Earthquake Ends a Seismic "Dry Spell" On Saturday, December 2, 2000, a magnitude 4.1 earthquake struck southern California. This was the first earthquake greater than magnitude 4 to occur since June 26, 2000. (www.scec.org/instanet/00news/news001206c.html)

SCEC: A Resource for California and the Nation. As version 1.0 of the Southern California Earthquake Center approaches its sunset and version 2.0 begins to take shape, we need to ask ourselves some important questions regarding our role in earthquake science and hazard analysis in southern California. (www.scec.org/instanet/00news/center001109.html)

LARSE II - One Year Later. This spotlight article begins with a brief history of LARSE I and II and then presents abstracts for posters shown at the 2000 SCEC Annual Meeting which highlighted the status of LARSE II results. (www.scec.org/instanet/00news/spot001018.html)

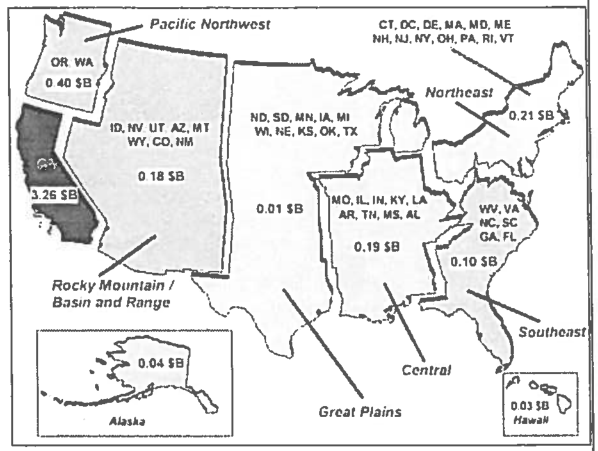
A Trio of October Earthquake Anniversaries. The halfway point in the month of October is a good time to reflect upon the lessons learned from previous California earthquakes; the anniversaries of three recent large earthquakes fall on consecutive days this week.. What did each of these three earthquakes teach us? (www.scec.org/instanet/00news/feature001018.html)

Earthquakes and Insurance, Then and Now. Those who sell earthquake insurance will undoubtedly tell you that if you provide earthquake coverage in California, it's a good idea to "plug in" to the earthquake research community. (www.scec.org/instanet/00news/relief001018.html)

The SCEC Transition. The Southern California Earthquake Center is undergoing a major transition. After a decade as a successful NSF Science and Technology Center, SCEC is about to enter its last year of STC funding. However, there is a strong consensus among scientists, users of earthquake information, and the sponsoring agencies that SCEC should continue as a major center for earthquake science. Several recent developments have encouraged SCEC to renew its charter. (www.scec.org/instanet/00news/center001010.html)

Table 1. Sample *SCEC InstaNET* articles on other topics (continued)

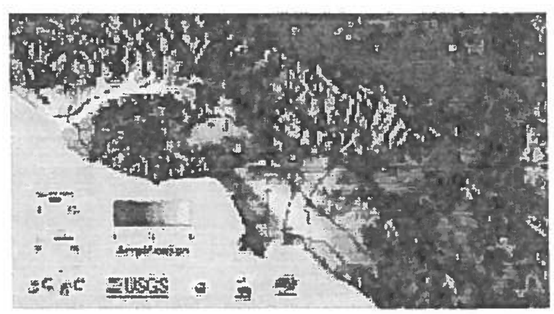
SCEC Response to FEMA 366 Earthquake Risk Report. This study estimates that the Annualized Earthquake Loss to the nation's building stock is $4.4 billion per year. The majority (84%) of the average annual loss is located on the West Coast (California, Oregon, Washington), with 74 percent ($3.3 billion per year) concentrated in the state of California and 25 percent in the County of Los Angeles alone. While we must not overlook the risk in other parts of the country, it is essential that we address the risk in southern California through the following actions:



- implementing aggressive retrofit programs for vulnerable buildings and structures,
- initiating a statewide nonstructural mitigation program for schools,
- maintaining a strong earthquake science and engineering research effort through continuing support to organizations such as SCEC, the USGS, the Consortia of Universities for Earthquake Engineering (CUREE), and the Pacific Earthquake Engineering Center (PEER), and
- continuing development of immediate response tools such as ShakeMap from TriNet to aid city and county emergency response teams in a post-earthquake setting.

(www.scec.org/instanet/00news/news000920.html)

SCEC Publication distribution. Copies of SCEC's field trip guides, technical reports (Phase I & II reprints, Liquefaction Mitigation Guidelines report, etc.), and *Putting Down Roots in Earthquake Country* general public brochure continued to be widely distributed at workshops, earthquake preparedness fairs, and through the SCEC website.



New for summer 2001 is the availability of the *SCEC Phase III Amplification* poster. The two most important factors influencing the level of earthquake ground motion at a site are the magnitude and distance of the earthquake. A new wall poster (30" x 36", $10) shows the influence of a third important factor, the site effect, where conditions at a particular location can increase (amplify) or decrease the level of shaking that is otherwise expected for a given magnitude and distance. (http://www.scec.org/outreach/products/index.html)

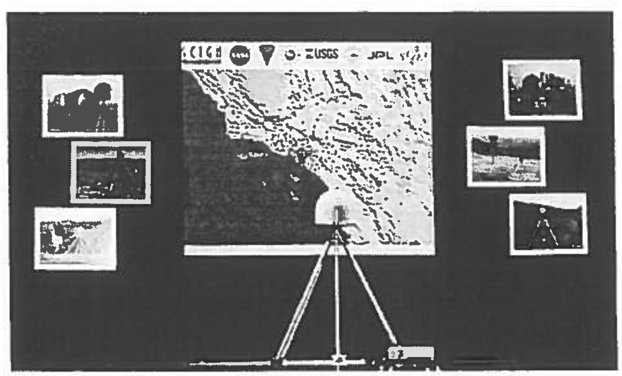
EqIP. SCEC Outreach participates in the EqIP (Earthquake Information Providers) group which connects information specialists from most earthquake-related organizations. EqIP's MISSION is to facilitate and improve access to earthquake information through collaboration; and minimize duplication of effort by sharing information through individual personal contact, joint activities and projects, group annual meetings and biennial forums, and electronic communication. SCEC managed the development of http://www.eqnet.org, EqIP's website which provides a database of descriptions of over 250 organizations with links to their websites. From 1998 to 2000, SCEC's Outreach Director chaired the steering committee for the group that oversees continued development of the website and other EqIP activities. In 2001, Mark Benthien developed an online survey of EqIP members to assess EqIPs success. (www.eqnet.org)

Objective 4: Foster a greater public understanding of earthquake risk

SCEC Phase III report Press Conference. The announcement of research that located "hotspots" of ground-motion amplification in the Los Angeles area turned the Davidson Executive Conference Center at USC into a kind of "media hotspot" on Tuesday, January 16, 2001, as reporters from over 30 different news organizations converged to hear what SCEC scientists had to say. The SCEC "Phase III" Report has quantified how local geologic conditions, known as "site effects," contribute to the shaking experienced in an earthquake.

SCEC CEO, Ned Field, Tom Jordan, Lucy Jones, and Lisa Wald developed a USGS/SCEC Fact Sheet and Press Release, planned the event, and provided a "b-roll" video tape of footage for use in news stories. An extensive web page was created for the event, which included high-resolution figures and movies, the fact sheet and press release, and links to the other information. News coverage of the event was collected into a post-event packet which included a video of television stories, clippings from newspapers, printed web-pages, and all materials provided at the event. (www.scec.org/phase3)

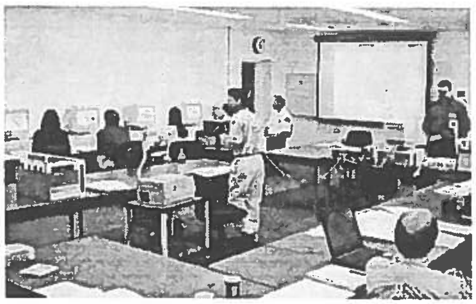
SCIGN Unveiling Event. On July 6, 2001, earthquake scientists unveiled the Southern California Integrated GPS Network (SCIGN), a new type of ground motion monitoring network. Unlike other instrument networks that record shaking, SCIGN tracks the slow motion of the Earth's plates by using the Global Positioning System (GPS), The 250th SCIGN station was installed on July 2, 2001.



SCEC CEO, working with a committee from USGS, JPL, Scripps, and Caltrans, produced the event. More than just a press conference, this event also included a display area, catered lunch, and tours to a nearby SCIGN station and laser strainmeter site. The committee managed the invitation of over 300 guests (100 atteneded), selected the location (Glendale Civic Auditorium), and organized a USGS fact sheet, press release, and extensive "b-roll" video tape of footage for use in news stories. An extensive web page was also created for the event, which included high-resolution figures and movies, the fact sheet and press release, and links to the other information. News coverage of the event was collected into a post-event packet which included a video of the event and television stories, clippings from newspapers, printed web-pages, and all materials provided at the Unveiling. (www.scec.org/scign)

New RELM Web Site. CEO staff assisted in the redesign of the new website for the SCEC/USGS working group for the development of Regional Earthquake Likelihood Models (RELM). RELM is the lead activity of the Southern California Earthquake Center (SCEC) in the area of seismic hazard analysis. (http://www.relm.org)

HAZUS. Over the past year SCEC has been moving toward greater use and understanding of Hazards US (HAZUS), FEMA's earthquake loss estimation software program. SCEC CEO is coordinating the development and activities of the Southern California HAZUS Users Group (SoCalHUG). with FEMA, the USGS, and OES. SoCalHUG is modeled on the existing San Francisco Bay Area HAZUS User's Group (BAHUG). It brings together current and potential HAZUS users from industry, government, universities, and other organizations to (a) train GIS professionals in HAZUS earthquake loss estimation software, (b) improve earthquake databases and inventories, and (c) develop and exercise emergency management protocol. SCEC is also considering how it can improve the data and models which HAZUS uses in its calculations. On April 26th, a "Kick-off Meeting" of SoCalHUG was held, and in late July a HAZUS training was held at California State University Fullerton for 23 Geographic Information System professionals employed by local governments, utilities, universities, and corporations. Funding for the training was provided by FEMA in response to a proposal by the SCEC and the OES.
(http://www.hazus.org, www.scec.org/instanet/00news/news001206b.html, and www.scec.org/instanet/01news/news010803.html)



International Conference on Disaster Management. This conference was held August 6-10, 2001 in Orlando, Florida. This conference was aimed at all emergency responders and will cover terrorism, hazmat, earthquakes, tornadoes, wildfire, flooding, volcanoes and hurricanes. Sponsors and Participants included: American Red Cross, FEMA, FBI, National Emergency Management Association, Institute on Business and Home Safety, National Domestic Preparedness Office and others. SCEC CEO organized three of the sessions on earthquakes: "Identifying the Earthquake Hazard", and "Being Prepared for Earthquakes." The first two sessions featured speakers from four regions of the country: Southern California, Pacific Northwest, Mid America, and the Northeast. The third session wastitled "Using HAZUS for Earthquake Risk Assessment." The sessions were conducted on Monday, August 6. Tom Jordan, Director Designate of SCEC, spoke about earthquake research in the 21st century during the general session on Tuesday, August 7. (www.scec.org/instanet/01news/news010702c.html)

AEG workshop on seismic hazard probabilities. This one-day short course on May 18 at USC was designed to provide greater understanding of probabilistic seismic hazard analysis (PSHA) and its applications. The course provided in-depth discussion of this specialized topic, in clear terms, with an emphasis on both fundamental and more advanced concepts. The course was jointly sponsored by the Association of Engineering Geologists (AEG), Southern California Section, and SCEC, and was intended for practicing earthquake professionals. In this course, Dr. Rob Sewell keeps unfamiliar mathematics to a minimum, and describes elements of probabilistic analysis in a transparent way, using familiar graphical illustrations of key concepts. The PSHA principles are explained and demonstrated with real-world examples that involve the application of PSHA software, such as the widely used program FRISKSP.

CEO activities through Jan 31, 2002

Develop Management Structure. Establish Leadership/Staff for E&O, plan collaboration with USGS E&O, and recruit E&O Advisory Committee.

Develop strategic plan. With E&O Advisory Committee and partners, develop 5-years specific goals and objectives, activities for Year 1, Year 2, and Years 3-5, and define how activities will achieve objectives/goals

Plan and prepare for assessment of all programs. 2001/2002: evaluation planning and pre-assessment (with experts). 2002-20XX: implement evaluation strategy, including evaluation of evaluation process

Develop spanish-language outreach plan. Identify spanish-speaking Community earthquake scientists (CICESE?) and identify methods that are most (cost) effective in reaching the spanish-speaking population

Strengthen E&O partnerships. Identify specific products/programs for which SCEC can provide input (public brochures, scenario development, etc.

Electronic Encyclopedia of Earthquakes. Continue development of the Encyclopedia and meet at AGU with potential contributors and advisors.

ShakeZone. Support the completion of the exhibit and announce the grand opening.

Seismic Sleuths. The online version of the revamped *Seismic Sleuths* curriculum will be compelted by November.

SCEC/USGS/IRIS Teacher Education Workshop. A one-day course on earthquake education conducted by SCEC and USGS, funded by IRIS. This will be the first of many planned workshops.

SCIGN Sign for Carrizo Plain. A permanent sign at the location of a SCIGN GPS instrument will be added to the *Wallace Creek Interpretative Trail.*

Earthquake Risk in LA. Complete and distribute this document written by a joint task force of SCEC and USGS Scientists, City of Los Angeles building officials, and the Structural Engineers Association of Southern California (SEAOSC).

SoCalHUG / SCEC HAZUS workshop. FEMA has funded a HAZUS workshop specifically for members of the SCEC Community to discuss how SCEC can contribute to the improvement of HAZUS. This meeting will be Nov. 13, followed the next day by a general meeting of SoCalHUG.

Support EERI 2002 scenario/assessment (February, 2002). The annual meeting of EERI will be held in Long Beach, CA, and will focus on the 1933 Long Beach earthquake. SCEC scientists are coordinating the development of improved scenarios for earthquakes on nearby faults, such as the Palos Verdes fault, for use in HAZUS assessments.

SCEC1 Highlights Document. CEO will support the completion of this extensive summary of the accomplishments of SCEC1.

SCEC Image Database. A searchable database of SCEC graphics, pictures, and other images will be online by December, 2001.

Prepare and plan for SCEC2 "Opening Ceremony". To announce the continuation of SCEC, CEO will coordinate the invitation of dignitaries, distribute a press release, and other logistics of the event. In advance of the event, CEO will complete an assessment and revamp of "SCEC InstaNET News", design a SCEC brochure, and redesign the SCEC Web pages.

A Fault Friction Driven Model of Crustal Stress in the Los Angeles Region

Brad T. Aagaard, Thomas H. Heaton, and John F. Hall
California Institute of Technology

We are using models of the dynamic friction on faults during earthquakes to create a model of the crustal stress in the Los Angeles region. The goal is to increment the displacement along the edges of the domain and allow earthquakes to control the evolution of the stress field within the volume. A wide variety of seismological and geodetic observations constrain the level of stress, including (1) rupture behavior, such as rupture speed and distribution of slip, inferred from kinematic source inversions of earthquakes, (2) the lack of heat flow found in exposed fault zones, (3) GPS and InSAR observations of plate motion, and (4) the need to support variations in topography and mass density. Comparison of synthetic strong ground motions with recorded motions will also provide feedback into the dynamic friction models.

The model relies on two principle components. Dynamic rupture simulations of earthquakes provide a test bed for evaluating how well various friction models produce realistic rupture behavior and allow computation of the perturbations in the stress field caused by the slip on the fault. Static simulations produce estimates of the background stress field from gravity acting on topography and density variations, strain accumulation due to plate motion, and slip during prior earthquakes. Successive earthquakes within the region and subsequent earthquakes on a single fault will play an important role in discriminating between different friction models.

Our preliminary results have focused on examining the behavior of ruptures with different friction models. We have found that (1) frictional sliding on fault surfaces is a highly nonlinear process that cannot be described by constant traction boundary conditions due to spatial and temporal variations in the magnitude and direction of the friction stress; (2) instantaneous healing of the fault upon termination of sliding accentuates the development of heterogeneity in the stress field and the distribution of slip; and (3) introducing rate-weakening behavior leads to pulse-like ruptures that tend to create stress fields and slip distributions with more heterogeneity for a given stress field than crack-like ruptures.

Small Earthquake Scaling Revisited: Can it Constrain Slip Weakening?

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We select 29 earthquakes well-recorded at 2.5 km depth at Cajon Pass (Abercrombie, 1995), including some colocated events. We compare spectral and time domain inferences of the source dimension to estimate final slip s and static stress drop ΔT. We measure radiated energy E_s by integration of the velocity-squared spectra using simple fits to extend the bandwidth outside the observed range to ensure we do not lose significant energy due to instrumental limits. (The E_s estimates of Abercrombie (1995) for earthquakes $Mo < 5 \times 10^{11}$ Nm are selectively biased to small stress drops, but otherwise the results are similar.) We compare the CJP results with those from larger California earthquakes including Northridge aftershocks and confirm Abercrombie (1995): for the smallest earthquakes, $\mu E_s / Mo << \Delta T$ (where μ = rigidity) and E_s / Mo increases more rapidly than ΔT as Mo (and also s) increases.

To interpret this we define a quantity $G' = [\Delta T - 2 \mu E_s / Mo] s / 2$ which is the total energy dissipation in friction and fracture minus $T_s s$, where T_s is the final static stress. If $T_s = T_d$, the dynamic shear strength during the last increments of seismic slip, then $G' = G$, the fracture energy in a slip-weakening interpretation of dissipation, with T_d then identified as the residual shear strength of Palmer and Rice (1973). Otherwise $G' = G + (T_d - T_s) s$. We find that G' increases with s, from ~ 10^3 J/m^2 at s = 1 mm (M1 events) to 10^6 to 10^7 J/m^2 at s = 1 m

(M6). An increasing rupture velocity with Mo cannot explain these results because it would imply unreasonably high ΔT for the small earthquakes.

We tentatively interpret these results within slip-weakening theory, assuming $G' \approx G$ (i.e., $T_s \approx T_d$). One explanation for these observations within the often assumed linear decrease of strength with slip, up to a slip D_c, is that either D_c, or the peak to residual strength drop $T_p - T_d$, or more generally $(T_p - T_d) D_c$, varies in proportion to the final slip s. This can match the observations, but implies the unlikely result that the weakening behavior of the fault depends on the final size of the earthquake. We also find that a single slip-weakening function $T(s)$ is able to match the observations, requiring no such correlation. Fitting G over $s = 1$ mm to 0.5 m with G proportional to $s^{(1+n)}$, we find $n \approx 0.1$ to 0.2. We show that this implies a strength drop from peak $T_p - T(s)$ proportional to s^n. This model also implies that slip weakening continues beyond the final slip s of typical events smaller than ~ M6, and that the total strength drop $T_p - T_d$ for large earthquakes is typically > 20 MPa and notably larger than ΔT. The latter suggests that on average the fault is initially stressed well below the peak strength, requiring stress concentration at the rupture front to propagate slipping. Other interpretations need to be explored outside the context of slip-weakening and allowing for dynamic over/undershoot.

Paleoshoreline Mapping and Estimates of Pleistocene to Holocene Uplift Along the Coast of the San Joaquin Hills, Orange County, California

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The San Joaquin Hills, Orange County, California have recently been identified as a seismically active source (Grant et al., in revision, BSSA) with a Late Quaternary uplift rate of 0.21 – 0.27 m/ka during the last 122,000 years (Grant et al., 1999; 2000; Geology). Recent mapping has revealed the presence of several shorelines below the stage 5 shorelines dated by Grant et al. (1999). The lower elevation shorelines may have formed during younger sea level highstands (stage 3 or Holocene) or they may represent co-seismic uplift events. If the age of the shorelines could be determined, it would be possible to measure the uplift rate of the San Joaquin Hills over several time intervals since 122 ka, or to estimate the recurrence interval for large earthquakes with co-seismic uplift.

We mapped and attempted to correlate several low elevation emergent shorelines along the coast of the San Joaquin Hills in a preliminary attempt to measure Holocene or Late Pleistocene uplift rates and estimate recurrence intervals of large earthquakes in the southern Los Angeles Basin. Shoreline elevations were estimated rather than measured for this preliminary study.

The lowest elevation emergent shoreline, designated the "1B" shoreline for our study, is approximately 1.7 m above the current active shoreline (1A). The 1B shoreline was previously measured and mapped by Grant et al., (in revision, BSSA) and correlated with emergent marsh deposits in Newport Bay that were radiocarbon dated as post-1635 A.D. This shoreline is interpreted by Grant et al., (in revision) as evidence of latest Holocene tectonic uplift associated with a M>7 earthquake, possibly in 1769 A.D.

A prominent shoreline, the "C" shoreline, was discovered in 17 locations at approximately 6.1 m to 9.2 m above the active shoreline angle (1A). Two additional shorelines, D and E, may exist at elevations of approximately 13 m and 16 m above the active shoreline, but they are poorly defined and more difficult to correlate between sites.

We developed several hypotheses for the age of each shoreline by attempting to correlate them with known sea level highstand stages and sub-stages. We then estimated uplift rates for each time interval based on the estimated (i.e. correlated) age and elevation of each shoreline. This preliminary analysis suggests that the prominent C shoreline does not correlate with either a stage 5 or stage 3 sea level highstand because the estimated uplift rates would be lower than those measured by Grant et al. (1999) using radiometric dating of stage 5 solitary corals.

Therefore, the C shoreline may correlate with the mid-Holocene highstand. This would imply late Holocene uplift rate as high as 1.1 m/ka, or Holocene coseismic uplift. In this correlation hypothesis, the D shoreline correlates with the sub-stage 3c sea level highstand, yielding an uplift rate of ~0.8 m/ka since approximately 60 ka. Our preliminary interpretation of the shorelines suggests that the uplift rate of the San Joaquin Hills has increased since 122 ka. Accurate elevation measurements and dating of the shorelines would be required to confirm or refute this preliminary assessment.

Array Analysis Reveals "Fault Zone Trapped Waves" Are Generally NOT Associated with the Fault

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Array analysis was used to determine whether fault zone trapped waves (FZTW) were generated from aftershocks of the 1999 Hector Mine earthquake. Previous studies have attempted to detect FZTW using visual inspection of the waveforms and frequency analysis alone. These methods cannot positively distinguish between FZTW and surface waves/scattered waves. Because array analysis determines the direction of arrival of seismic waves, this method aids in distinguishing true FZTW from surface waves/scattered waves that exhibit FZTW-like characteristics. A two-dimensional array in the Bullion Wash was deployed following the Hector Mine earthquake. The array of 47 seismometers consisted of a dense linear array laid out perpendicular to the fault and a 2D array with 25 elements. The horizontal components of the seismometers were oriented at 315 and 45 degrees, approximately parallel and perpendicular to the fault, to best observe FZTW. Although hundreds of aftershocks were recorded on the array, 27 were selected for analysis. Each had its epicenter close to the fault; each showed FZTW characteristics—large amplitudes after the direct S wave, a decay in amplitude away from the fault and a peaked Fourier amplitude spectrum (Li et al., 1994). Timing corrections, based on earthquakes located below the array, were applied to each record to correct for the effect of heterogeneity beneath the array. After applying these corrections, the mean error of the S wave back azimuth, pointing to the epicenter, was reduced to four degrees. Array analysis was then applied to the fault parallel component of ground velocity from these aftershocks. Of these 27 aftershocks, only 6 produced a FZTW-like wave packet that originated from a direction consistent with the fault strike and epicenter. For 21 aftershocks, the FZTW-like waves arrived from directions well off the fault, suggesting that these packets are basin trapped waves. By itself this shows that FZTW can easily be misidentified using visual inspection and frequency characteristics alone. But more analysis of these 6 aftershocks further reduced the viable candidates for FZTW. For one event (99309021324), array analysis showed a time dependence of the azimuth FZTW-like wave arriving from the direction of the fault due to scattering. Of the 27 aftershocks, only one unambiguously showed the characteristics of the FZTW as well as coming from the direction of the fault. Two others were possible candidates. Thus, optimistically, only 10% of the candidates for FZTW, based on visual inspection of the waveforms, are possible FZTW. Further analysis of the wave packets may reduce the percentage of viable candidates to 3-4% or less. What the array analysis cannot confirm for the viable candidates is that the radiation comes from a progressive translation of the source along the strike as might be expected for a FZTW.

Importance of the Ergodic Assumption in Probabilistic Seismic Hazard Analysis

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Anderson and Brune (1999) proposed that the ergodic assumption could be significant in causing probabilistic seismic hazard analyses (psha) to overestimate the hazard at low probabilities. By the ergodic assumption, we mean a random process in which the distribution of a random variable in space is the same as its distribution at a single point when sampled in multiple experiments. In psha, regression analysis develops a mean curve to estimate ground motions, as a function of magnitude and distance, and infers the standard deviation of the estimate by the misfit of multiple stations in a relatively small number of earthquakes, making the standard deviation primarily a spatial variable. In psha, if the standard deviation is treated as an aleatory uncertainty, an ergodic assumption is made, while if it is treated as an epistemic uncertainty, the ergodic assumption is avoided. In this study, we seek to test this assumption through numerical tests in which the uncertainty is treated as either entirely epistemic (with uncertainties correlated) or entirely aleatory. One case we test is for a site reproducing the geometry of Lovejoy Buttes, 15 km from the San Andreas fault. Calculations include hazard curves for 50 years and for 10,000 years, motivated by the typical engineering applications and by the approximate lifetime of semiprecarious rocks at Lovejoy Buttes, documented by Brune (1999) to be unstable for peak accelerations in excess of about 0.4g. Another case we test is for a more typical site within a diffuse source zone and also affected by several nearby faults. For these examples, for probabilities in the range of 2% to 10% in 50 years, the upper limit on the effect of the ergodic assumption was to increase the ground motion by about 30%, which could be a significant effect for code applications. For psha focused on probability of exceedance in 10,000 years, the difference was greater. In particular, for this analysis the results practically avoid the contradiction between the psha and the existence of the precarious rocks.

First Actual Field Test of Predicted Toppling Accelerations for Precarious Rocks Provided by the 1999 Hector Mine Earthquake

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An approximate field test of the precarious rock methodology has been provided by the M_s=7.1 Hector Mine earthquake of 16 October 1999 (Brune, 2001). The Hector Mine earthquake was a rare event on very low slip-rate faults near the eastern edge of the Eastern California Shear Zone. Preliminary trenching information indicates that the major fault segments that ruptured in this event had not ruptured in a similar event for more than 10 ka years (Lindvall et al., 2001; Rymer et al., 2001). Brune (1996) identified precarious rocks at Granite Pass, approximately 20 km northeast of the Bristol Fault, and classified them as ``precarious'', i.e., could be toppled by earthquake ground accelerations of less than 0.3~g, typically about 0.2~g (site number 3 in Brune, 1996). A photograph of three of the rocks was published: Figs. 2d and 2e of Brune (1996). The rock in Fig. 2e was apparently toppled by the Hector Mine earthquake (along with another nearby rock for which the photograph was not published). The quasi-static toppling acceleration estimated geometrically from photographs is about 0.2~g. The Amboy strong motion record from the Hector Mine earthquake, at approximately the same distance and the same general direction, recorded a peak ground acceleration of about 0.2g (Grazier et al., 2001, --actually 0.18~g measured from the seismogram available on the internet). The Intensity at Granite Pass is about I = V (Dewey, personal communication). Recent regressions of peak acceleration vs. Intensity, give an acceleration of somewhat less than 0.1~g, with considerable scatter. Both observations are consistent with the designation of the rocks as "precarious" by Brune (1996).

We use the Amboy accelerogram , along with small Hector Mine aftershocks recorded at both the Amboy site and at Granite Pass sites, to make a rough correction for differences in path and site effects. The Granite Pass site (on solid granite) is richer in high frequencies than the Amboy site (underlain by layered volcanics and alluvium), but lower in peak velocity. The estimated acceleration at Granite Pass is about 0.12~g, as compared to the original Amboy accelerogram peak value of 0.18~g.

Using two small earthquakes to estimate the transfer function does not take into account effects such as directivity, non-linearity and Moho reflection which might have been present in the main event. A more accurate estimate may be possible once we have recorded more aftershocks at both stations.

Basin-Fault estimation of the Santa Monica Area using an 3D Tomographic Algorithm

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The Santa Monica Mountains and surrounding area has had a complex tectonic history including the transition from strike-slip to extensional to transpressional tectonics. To better understand the complex subsurface structure in Santa Monica and its effect on wave propagation we conducted LARSE-HRESS, a high resolution seismic survey. The experiment took place in two parts: 1) a refraction survey in October 1999 that involved recording arrivals from shots and earthquakes (including Hector Mine) on a 194 sensor array; 2) a 10 km Vibroseis reflection survey in June 2000 through Santa Monica and Pacific Palisades with vibes every 60 m and geophones every 30 m. First p arrivals from shots and vibes have been used as input to a local earthquake tomography algorithm that generated 3D images of a fault-basin structure in the Santa Monica Mountains and adjacent area. These images detail the existence of two basins 1) Spherical shaped basin that is located beneath the damage zone and extends to 3 km depth; 2) Cylindrical shaped basin to the southeast is larger and presumed to be the edge of the Los Angeles basin. We located the Santa Monica Fault at depth, about 1 km north of the location of a surface trace that was previously mapped. Ray tracing through the 3D velocity structure confirmed the existence of deep structural focusing of seismic energy beneath the damage zone as a result of the Northridge earthquake.

New constraints on tectonic contraction across Los Angeles after removal of groundwater pumping effects

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We augment the SCIGN time series for the greater Los Angeles region with Interferometric Synthetic Aperture Radar (InSAR) imagery to search for evidence of blind thrust faulting. After removing the deformation associated with groundwater pumping and strike-slip faulting, we find 4.4±0.8 mm/yr of N36±5°E-oriented uniaxial contraction across the Los Angeles basin, perpendicular to the major strike-slip faults. This suggests that the contraction is primarily accommodated on thrust faults rather than on northeast-trending strike-slip faults. The contraction rate is smaller and rotated 36° clockwise from that determined by Argus et al (Geology, 1999). This difference arises because, in addition to the San Andreas and San Jacinto faults, we also included interseismic slip on the Palos Verdes, Newport-Inglewood, and Whittier faults to minimize right-lateral GPS displacement gradients. Argus et al. used a smaller GPS data set to infer that regional contraction is confined to a 30-km-wide zone between the San

Gabriel Mountains and downtown Los Angeles, but we find that the GPS sites needed to resolve the southern boundaries of the contraction region are contaminated. Walls et al. (Nature, 1998) argued that no more than half the geodetically observed contraction, or <2.5-3.5 mm/yr, is due to thrust faulting, with the remainder accommodated by conjugate strike-slip faults in the northern Los Angeles basin. We find that the residual contraction is larger than inferred by Walls et al., and because the NE-oriented contractional strain rate (56±7 nanostrain/yr) is eight times larger than the NW-oriented extension rate, the residual contraction can not be explained by unmodeled strike-slip faulting. Instead, the contraction is optimally oriented to accommodate slip on the regional blind and surface-cutting thrust faults.

The widespread groundwater and oil pumping obscures and in some cases mimics the tectonic signals expected from the blind thrusts. In the 40-km long Santa Ana basin, groundwater withdrawal and re-injection produces 12 mm/yr of long-term subsidence, accompanied by an unprecedented 55 mm of vertical and 7 mm of horizontal seasonal oscillations. Further densification of the SCIGN net outside the subsidence zones may enable discrimination of competing thrust fault models, which will be vital to seismic hazard assessment.

Criticality, Intermittent Criticality, and Quantification of an Earthquake Cycle with Evolving Stress Correlations

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Various studies suggest that large earthquakes occur when a fault system reaches a critical state associated with the establishment of long-range stress correlations. We quantify this process using stress and earthquakes histories generated by the model of Ben-Zion (JGR, 96) for a discrete heterogeneous strike-slip fault system in a 3D elastic half-space. Analytical and numerical results have shown (Fisher et al., PRL, 97; Dahmen et al., PRE, 98) that the model has an underlying critical point at critical values of two tuning parameters: zero dynamic weakening (i.e., static friction = kinetic friction) and full conservation of stress transfer during failure events. Numerical simulations with various cases of smooth and heterogeneous faults (Ben-Zion and Rice, JGR, 95, 97) suggest further that the level of disorder in fault heterogeneities is another tuning parameter. To quantify stress evolution associated with ongoing seismicity we analyze results of 3 model realizations. The first has a fractal distribution of strength heterogeneities and realistic non-critical dynamic weakening. The second has the same fractal strength heterogeneities but critical dynamic weakening. The third has uniform strength properties, non-critical dynamic weakening, and is constrained to produce only system-size events. The first case is the primary target for detailed analysis, while the other two are "control" cases allowing us to examine changes in the dynamics associated with values of tuning parameters and to separate evolution due to ongoing seismicity from that associated with gradual tectonic loading.

In each case we analyze the temporal evolution of five functions: (1) standard deviation of stress on the fault, (2) configurational entropy of occupied states of stress, (3) order parameter based on stress fluctuations, (4) 2D spatial power spectra of stress, and (5) frequency-size statistics of earthquakes. The results for the first case show non-repeating cyclic establishment and destruction of stress correlations on the fault, punctuated by the occurrence of system-size events. This is manifested by increasing values of functions (1)-(3), transfer of power spectral energy from long to short wavelength components, and occurrence of increasingly larger events that broaden the power-law range of frequency-size statistics. Most functions reach a maximum or saturation around 2/3-3/4 of a large earthquake cycle (e.g., the spectral energy at such times is more-or-less equally distributed over all wavelengths) and then fluctuate there until one small event cascades to become the next large earthquake. For the second case with dynamic weakening at the critical value, the discussed cyclical evolution is replaced by statistical fluctuations. In the third case with only system-size events, some functions have simple cyclical behavior (with different structure than for the first case) and others do not. The results suggest that dynamics of heterogeneous faults is associated with intermittent criticality produced by ongoing seismicity that transfers energy from long wavelength produced by the tectonic loading to a broad range of sizes. The evolving stress heterogeneities become increasingly closer to a critical level of disorder developing simultaneously long-range correlations. Continuing analysis of this process, combined with quantitative analysis of associated seismicity signals, may provide new target signals for statistical forecasting of large earthquakes.

SCEC Activities at SOPAC

Yehuda Bock, Peng Fang, Jeff Genrich, Brent Gilmore, Paul Jamason, Rosanne Nikolaidis, Linette Prawirodirdjo, Michael Scharber, Matthijs van Domselaar

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SOPAC provides ongoing infrastructure support for geodetic studies of crustal deformation in southern California under the umbrella of SCEC's Southern California Integrated GPS Network (SCIGN). We have responsibility for archiving SCIGN GPS data, parallel responsibility (with JPL) for generating daily position time series, and responsibility for maintaining 20% of SCIGN sites (the other 80% maintained by the USGS).

SOPAC archives and disseminates raw and RINEX data for all SCIGN sites, as well as RINEX data collected by the other continuous GPS arrays in Western North America and the International GPS Service (IGS). The current capacity of the archive totals about 2 TB of online storage. Continuous GPS data are routinely sampled and archived at a 30 second interval. All data in the archive (since 1990) are available online. Retrieval of continuous GPS RINEX files is running between 350,000-550,000 transfers per month.

Highlights over the last year include:

(1) Conversion of all RINEX data on the SOPAC archive to Hatanaka compressed format. The main benefits of moving to this compression strategy for our RINEX observation files are a significantly decreased storage requirement (Hatanaka-Unix-compressed RINEX observation files can take as little as 25 to 30% of the space that a standard Unix-compressed file would require), and a significantly decreased network load (as a result of the storage improvement).

(2) Complete redesign of the SOPAC Web Site (moved from lox.ucsd.edu to sopac.ucsd.edu). The new site, besides its improved look and easier navigation features, contains many new applications for site maintenance, archiving, site and download statistics, analysis, and display. For example, we have implemented a new mapserver, made our coordinate time series files available, published a weekly SCIGN data newsletter, and implemented a utility for querying file transfer statistics.

(3) Use of the method of instantaneous positioning described by *Bock et al.* [2000] to measure dynamic displacements of SCIGN sites due to the Hector Mine earthquake [*Nikolaidis et al.*, 2001]. As a direct result of this work, we have begun to increase by a factor of six the sampling rate of a subset of the SCIGN stations to 5 s. The raw data is stored at this higher rate in the archive but is decimated to the standard 30 s sampling interval when converted to RINEX format. This higher rate data is also useful to the surveying, engineering, and GIS communities in southern California and is made available to users through the California Spatial Reference Center.

References

Bock, Y., R. Nikolaidis, P. J. de Jonge, and M. Bevis, Instantaneous resolution of crustal motion at medium distances with the Global Positioning System, *J. Geophys. Res.*, *105*, 28,223-28,254, 2000.

Nikolaidis, R., Y. Bock, P. Shearer, P. J. de Jonge, D.C. Agnew, and M. Van Domselaar, Seismic wave observations with the Global Positioning System, J. Geophys. Res., in press, 2001.

Seismic Behavior of Oceanic Transform Faults

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We have conducted a comprehensive global investigation of oceanic transform fault (OTF) seismicity, which confirms that OTFs have fundamentally different seismic properties than continental transform faults (CTFs). We investigated frequency-magnitude relations, aftershock productivity rates, and the percentage of slip accommodated seismically for 75 OTFs using data from the International Seismological Centre, Harvard Centroid Moment Tensor Project, Oregon State University Moment-Tensor Solutions, and NOAA-PMEL/T-phase Project catalogs. OTFs have depleted aftershock sequences, high seismic deficits (~85%), few large earthquakes, low b-values (~0.85), and depleted high-frequency energy content compared to CTFs. Only ~15% of the slip on OTFs can be accounted for with typical high-frequency earthquakes, while CTFs (e.g. San Andreas and North Anatolian) have been shown to be fully seismic (i.e. no seismic deficit). No OTF earthquake greater the M_w 7.2 has occurred during the past 37 years and no evidence was found for characteristic earthquake behavior. We observed, on average, less than one mb ≥ 4.5 aftershock per large OTF earthquake. The limited (~4 years) equatorial Pacific T-phase data show that while many small aftershocks are detected following some events (e.g. M_w 5.9 on the Gofar TF), other OTF earthquakes have no recorded T-phase aftershocks (e.g. M_w 6.2 on the Gofar TF).

Maximum event magnitude, seismic deficit, and *b*-value we observed to vary with slip rate on OTFs. These trends are likely to be related. Maximum event magnitude decreases with slip rate, thereby resulting in both high seismic deficits and sharp roll-offs in the frequency-magnitude distribution. High slip rates, seismic deficits, and the lack of large earthquakes require processes such as steady aseismic creep and slow aseismic transients to produce much of the log-term offset, especially on fast slipping transforms. The above properties suggest that OTFs can be characterized by a low degree of seismic heterogeneity, indicating a smooth rupture process and relatively little structural complexity.

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InSAR Observed Deformation along the Coyote Creek Fault, Imperial County

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Interferometric synthetic aperture radar (InSAR) measurements show a consistent, 40 km^2 wedge-shaped area of deformation partially bounded by a branch of the Coyote Creek fault (a southern extension of the San Jacinto fault) in Imperial County, California west of the Salton Sea. The deformation is centered at 33.1 N latitude, 116.0 W longitude. 11 ERS-1 and ERS-2 pairs between 1992 to 2000 are analyzed. A roughly 10-mm line-of-sight range change per year is observed. The western edge of the deformation is bounded by a mapped fault that ruptured in the 1968 M_w 6.5 Borrego Mountain earthquake. The area of deformation also coincides with a farming area that pumps substantial quantities of groundwater from 5 wells on the property. Between 1995 and 1997 the average rate of pumping was approximately 4.7×10^6 m^3 per year. The area of highest change appears to be centered on location of the wells and away from the boundaries. The aquifer is at a depth of roughly 100 to 200 m and consists of sands with interbedded clays. Clays comprise approximately 20% of the well log. It appears that the most likely explanation is subsidence due to groundwater withdrawal and compaction of fine-grained layers. Preliminary calculations suggest that these effects can easily explain the magnitude and geometry of subsidence. The south edge of the deformation is also a sharp boundary, suggesting that it is also bounded by a fault that has been active since deposition of the aquifer. SAR data from the WINSAR consortium was used for this study.

Simultaneous Determination of Calibration Parameters for an Airborne LIDAR Imaging System

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Kenneth Hudnut (US Geological Survey, Pasadena)

High-resolution LIDAR mapping of the 1999 Hector Mine Earthquake fault zone by the USGS has provided geologists with an unprecedented data set for examining the surface expression of a large strike-slip earthquake. Overlapping areas of "ground truth" measurements derived from GPS have made this data set an ideal tool for testing a new method of LIDAR calibration which simultaneously determines all calibration parameters using analytical optimization techniques.

Traditional calibration of airborne LIDAR involves measuring different types of parameters separately, using any one of several unrelated methods. However, If a complex surface being mapped by LIDAR is known a priori, then comparison between the LIDAR-derived elevations and the known elevation of this "ground truth" surface can be used to calibrate the entire LIDAR system. The calibration can be looked at as an optimization problem which minimizes the difference between the ground truth and LIDAR measurements.

The problem is set up using a standard geolocation algorithm for scanning airborne LIDAR, with analytical expressions for the partial derivatives of each of the calibration parameters to be estimated. A variety of optimization methods exist for solving this type of problem. We explicitly include a representation of the ground truth surface and its gradient in the formulation of the problem, which would not be necessary if the ground truth surface were flat. Although a flat surface simplifies the analytical problem and is easy to measure in the field, many of the parameters become highly correlated in that case, and cannot be independently determined with geodetic accuracy.

One major strength of the Hector Mine data is the availability of excellent ground truth in the area of the Hector Mine itself, which was overflown several times in different directions for the express purpose of enabling this type of calibration. The intent of our research with this unique data set is to develop an effective and straightforward calibration tool for any airborne LIDAR system.

Stress Accumulation and Seismicity Before Large Earthquakes: A New Model

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We describe a simple physical model that links static stress modeling to the seismicity observed throughout the seismic cycle in a broad region around a major fault. The model consists of a Coulomb stress field generated by a combination of loading of the fault by adjacent faults and creep at depth. This Coulomb field, which evolves with time, is further modulated by a random inhomogeneous stress field that also varies with time. Unlike conventional Coulomb modeling, the stresses added to the inhomogeneous field are related to a failure stress rather than stress change. This is achieved by applying a correction to allow for background stress and pre-existing stresses in the fault region due to tectonic history. Stress concentrations above a simple failure threshold produce earthquakes that can be appropriately scaled to produce a Gutenberg-Richter distribution of background seismicity. These stress fields are calculated for a series of time increments through the earthquake cycle, and control the distribution of events throughout the cycle.

The models accurately simulate the form of accelerated moment release before large earthquakes and other features of the entire seismic cycle, such as aftershocks, inter event quiescence and Mogi doughnuts. The generic model presented can be readily adapted to specific cases where sufficient data is available.

FAULT-NORMAL DYNAMIC UNLOADING AND LOADING: AN EXPLANATION FOR "NON-GOUGE" ROCK POWDER AND LACK OF FAULT-PARALLEL SHEAR BANDS ALONG THE SAN ANDREAS FAULT

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Some faults with tens of km of displacement appear to have fault-slip planes only centimeters wide, e.g., the Punchbowl fault in southern California. On the other hand, the nearby San Andreas fault between San Bernardino and Tejon Pass has a zone of powdered rock typically over a hundred meters wide. The powdered rock has been described as "gouge", shearing, milling, comminution, or grinding between the two sides of the fault, a process observed in rock mechanics experiments. Large-displacement rock mechanics experiments typically develop a narrow zone of gouge consisting of fine-grained rock fragments with thin fault-parallel shear bands, which localize the slip. It is tempting to interpret the San Andreas fault "gouge" as a very-large-scale phenomenon of the same type, but observations suggest that this is not the case.

A careful reconnaissance survey of more than ten sites along the San Andreas Fault between San Bernardino and Tejon Pass resulted in the following observations: (1) There are no obvious shear planes or bands parallel to the San Andreas fault, (2) at distances from 1 m to 200 m from the fault the original gneissic or granitic structure appears to be undisturbed at all scales, in particular un-sheared, this in spite of the fact that it consists almost entirely of fine-grained powder,--suggesting that the rocks were powdered in place without shear distortion, (3) the powder occurs only in geniuses and granites, not in shallow forming rocks, and (4) the rock powder contains myriads of fine-scale conjugate shear bands corresponding to a principal stress normal to the San Andreas fault.

A mechanism for explaining these surprising facts is dynamic fault-normal unloading and loading, i.e., when the rocks were deeper along the fault they were cyclically dynamically unloaded and loaded by an opening mode dislocation (or a similar drastic drop in normal stress). An opening mode dislocation has previously been suggested as an explanation for the "heat flow paradox", i.e., the lack of any observable frictional heat from San Andreas fault-slip. If such an opening mode (or drop in normal stress) exists, the rocks close to the fault may have been exposed to a nearly instantaneous drop in confining stress of the order of kilobars during many earthquakes, turning to dust with very little associated shear. This mechanism would explain why shallower rocks in fault zones do not develop gouge. Thus the actual San Andreas fault-slip zone is very narrow, similar to that of the nearby Punchbowl fault. Dynamic unloading and loading may also explain other features of strike-slip faults, such as fault troughs, sag ponds, and large-scale fault-normal compressive features. If this proposed mechanism is correct, it explains both the fault gouge "paradox" and the heat flow "paradox".

Advantages of Combining Geodetic and Seismic Data in the Analysis of the 1999 Chi-Chi Earthquake Rupture process

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Source rupture history models of large earthquakes have been derived by direct inversion of seismic data only or combined with geodetic data. During the study of 1999 Chi-Chi earthquake, we found that the addition of the static field proved extremely helpful in fixing the faulting offsets so that rise time and rupture velocity variations could be addressed more accurately. First, even though the strong motion dataset of this event is the best ever recorded, the fault geometry can be determined uniquely only with the static inversion. In fact, fault geometry determined using the geodetic data successfully explains some of the puzzling seismic observations. Second, a layered 1D approximation to 3D Earth structure provides an adequate first-order representation of the surface displacement field, but is inadequate for reproducing recorded ground velocities in some regions. The combined inversion will, however, prevent extremely large slip amplitudes that compensate for those velocity records with large site amplifications. Adding the static data into the study of mainshock rupture models is not always positive, i.e., the static data can be biased by afterslip. We will show how the combined inversion result of the Chi-Chi event is a good example of such afterslip contamination for a particular fault segment. However, studying seismic and geodetic data together can provide a much clearer picture of the fault process and the nature of strong ground shaking.

A Numerical Asperity Model for Repeating Earthquakes

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The numerical model developed by *Ben-Zion and Rice* [1993] is used to simulate a cluster of asperities on a creeping fault plane. For constant loading rate, the cluster produces repeating events having a period T that scales with moment M_0 as $T \propto M_0^{1/6}$. This is the same scaling observed by *Nadeau and Johnson* [1998] at Parkfield and derived analytically by *Johnson and Nadeau* [2001] for solid asperities. However, for asperity clusters we found that the constant of proportionality in this scaling relation depends on the density of asperities within the cluster (defined as the ratio of the total area of the asperities to the total area of the cluster). Hence, only clusters with a fixed asperity density follow $T \propto M_0^{1/6}$ scaling. This implies that if repeating earthquakes are associated with stuck asperities on a creeping fault plane, they are probably solid asperities and not clusters. For solid asperities, the average stress drop on the asperity decreases with increasing asperity radius r_a as $r_a^{-1/2}$. However, when stress is averaged over the entire slip surface, which includes the low-stress region surrounding the asperity, the average stress drop is much lower, and decreases more rapidly with increasing asperity radius as $r_a^{-3/2}$.

A Quantitative Measure of Complexity in the Surface Traces of Fault Zones

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The observation of structural heterogeneities in fault zones is ubiquitous. Heterogeneities play important roles in the mechanics of faulting before, during, and after earthquake ruptures. It is thus important to obtain quantitative measures of structural heterogeneity. Wesnousky [BSSA, '94] and Stirling et al. [GJI, '96] characterized structural complexity as the density of steps per unit distance along the surface traces of faults. The density, however, does not provide a full characterization of the structural complexity. Ben-Zion and Rice [JGR, 93, 95] suggested that a better parameter may be the range of size scales characterizing the heterogeneities. Since the equations of elasticity governing stress transfer are scale invariant, mere changes of all length scales uniformly, including the density of fault offsets, only shifts the response to different scales without changing the response type (e.g., the form of earthquake statistics). On the other hand, changes in the range of size scales can both shift and change the form of the response.

In the present work we quantify structural complexity in several California fault zones using the range of scales in the distribution of fault segment angles and lengths. For each fault segment mapped at the surface, we measure the angle between the segment trend and the regional plate motion direction. For lengths, we measure both the along-strike length of a fault segment and the projection of that distance in the direction normal to the plate motion. We established a systematic method of measurement employing computer codes used in conjunction with the program "ArcView", designed to find length and orientation of fault segments from digital fault maps. In general, complexities are expected to depend on the following three variables: 1) Misalignment of the overall fault zone direction from the plate motion; larger misalignment will tend to produce greater complexity. 2) Total slip accommodated by the fault zone; large cumulative slip will tend to reduce the complexity. 3) The ratio of the time scale of healing to the time scale of loading; large ratios will lead to regularized structures and small ratios will produce disordered fault systems [Ben-Zion et al., EPSL, '99; Lyakhovsky et al., JGR, '01].

In the work done so far, we analyzed data from the following faults: the San Andreas, Hayward-Maacama, Calaveras-Bartlett Springs, Garlock, Whittier-Narrows, Newport-Inglewood-Rose Canyon, and San Jacinto. Assuming that the ratio of time scales of healing to loading is similar for all of those faults, we separate them into two categories according to the amount of relative misalignment. Fault zones of relatively high misalignment include the San Jacinto, Garlock, and Southern San Andreas, while fault zones of relatively low misalignment are the Hayward-Maacama, Calaveras-Bartlett Springs, Whittier-Narrows, and Newport-Inglewood-Rose Canyon faults. Within each category, we find that the range of segment angles in a fault system decreases with increasing cumulative slip. Continuing analysis of this and other measures on a larger population of faults may help clarifying which structural parameters provide useful characterization of the evolutionary state, and hence mechanical potential, of a fault.

Towards a Combined Mechanical and Geodetic 3-D model of Los Angeles Basin Faults

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A three-dimensional model of the fault configuration in the Los Angeles Basin is constructed based on arrays of 2-D cross-sections published by other researchers [Davis, Namson & Yerkes (1989); Oskin et al. (2000); Shaw & Suppe (1996); Wright (1991)]. The boundary element numerical model Poly3D is used to assess the response of this fault configuration under horizontal contraction, in order to simulate conditions in the Los Angeles

Basin. In Poly3D, traction-free faults are simulated within an homogeneous elastic half-space. Deformation of this system under two contraction rates and directions, north-south (Fiegl et al, 1993, Argus et al 1999) and N36E (Bawden et al 2001), are evaluated. The change in fault slip rates under these two boundary conditions gives evidence to the sensitivity of the fault system to contraction direction. Calculations of uplift rates as well as sense and magnitude of slip on exposed faults are compared to available paleoseismic data. Slip sense along all faults is consistent with paleoseismic data. Modeled slip rates along the Santa Monica, Hollywood and Newport-Inglewood faults are within the range of observations. Underestimation of strike-slip along the Whittier fault and overestimation of Palos Verdes dip-slip within the model may be a consequence of inaccurate fault geometry.

The mechanical Boundary Element Method (BEM) models of fault slip simulate deformation on geologic time scales incorporating many earthquakes. We need to compare these velocities to the best data sets available. SCIGN, with its set of permanent GPS stations focused on the Los Angeles basin, will provide three-dimensional measurements of surface velocities at an unprecedented level of accuracy. However, the SCIGN and InSAR data reflect interseismic strain accumulated in a few years between earthquake events. For this reason a direct comparison of the model predicted surface strains and geodetic results is not possible; however, we present an innovative methodology that approximates long-term secular velocities at the base of the brittle crust using a horizontal crack within the model. We estimate of interseismic velocities in two steps: first, the long-term geologic deformation along a slipping surface (crack) at the locking depth is determined and second, we prescribe these long-term velocities along a surface at the locking depth below an unfaulted elastic crust to estimate interseismic strain. We first test this methodology against previous analyses of isolated vertical strike-slip faults; after validating the methodology, we will use this approach to calculate interseismic strain accumulation associated with different models of the Los Angeles Basin fault system.

Paleoseismologic Evidence for Latest Pleistocene-Holocene Earthquake Occurrence in the Greater Los Angeles Metropolitan Region: Towards a Preliminary Understanding of Strain Release in Time and Space

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Three major fault systems accommodate strain in the Los Angeles metropolitan region: (1) northwest-trending, right-lateral strike-slip faults in the south (San Jacinto, Whittier-Elsinore, Newport-Inglewood, and Palos Verdes faults); (2) a west-trending system of left-lateral and oblique-reverse faults (Raymond, Hollywood, Santa Monica, and Anacapa-Dume faults) that extends along the southern edge of the Transverse Ranges and accommodates westward extrusion of the Santa Monica Mountains block; and (3) a system of west-trending reverse faults that bounds the northern edge of the metropolitan region (Cucamonga, Sierra Madre, Verdugo, Northridge, and Santa Susana faults) and extends westward into the Ventura Basin (Oak Ridge and San Cayetano faults).

Although still incomplete, paleoseismologic studies, many of them conducted under the auspices of SCEC, have begun to reveal late Pleistocene-Holocene patterns of strain release in time and space on this complicated network of faults. Within the LA region, none of these studies have yielded evidence for surface ruptures on any of the studied faults in at least 1,000 years, consistent with the idea that the historic period has been relatively quiet seismically. Paleoseismologic data from the Raymond, Hollywood, and Santa Monica faults indicate, however, that all three of these faults generated surface ruptures between ~1-3 ka (Crook et al., 1987; Dolan et al., 1997; 2000a; 2000b; Weaver and Dolan, 2000; Lindvall et al., 2001). The Whittier fault also generated a surface rupture at ~2 ka (Patterson and Rockwell, 1993), and the Newport-Inglewood (Grant et al., 1997) and Palos Verdes (MacNeilan et al., 1996) faults may also have ruptured during this time. These results suggest that a short-lived cluster of events occurred ~2 ka on a sub-set of faults grouped around the Los Angeles basin. In marked contrast to the circum-LA Basin faults, trenches excavated across the eastern Sierra Madre fault indicate that the most recent surface rupture there occurred ~8-10 ka (Tucker and Dolan, 2001; Dolan and Tucker, in prep.). The current very long quiescent interval is consistent with data from a site 50 km to the west along the central reach of the Sierra Madre fault, where Rubin et al. (1998) report the occurrence of only two large-displacement (Mw >7) surface ruptures during the past 15 ka. Observations from the Cucamonga fault (Dolan et al., 1996) reveal that this fault has ruptured to the surface at least twice, and probably several times since the most recent Sierra Madre fault surface rupture. Similarly, the Raymond fault has generated at least one, and probably several surface ruptures since the 8-10 ka event on the eastern Sierra Madre fault (Weaver and Dolan, 2000).

In the Ventura Basin, paleoseismologic data demonstrate that a large-displacement (Mw >7) surface rupture occurred on the eastern San Cayetano fault after 1660 A. D. (Dolan and Rockwell, in press). This may have been the historic December 21, 1812 earthquake. Alternatively, this event could have occurred during the century immediately preceding the historic era. This would suggest the possibility of at least two large-magnitude events in the western Transverse ranges during the past few hundred years, in marked contrast to the apparent absence of such large events over the past 1,000-plus years in the Los Angeles region. Such temporally complicated strain release is an expected consequence of the mechanically complex nature of the plate-boundary in southern California, where elastic strain buildup on each fault is a complicated mixture of tectonic loading (which may, or may not be relatively continuous) and stress interactions with ruptures on other faults throughout the system (which is, as shown by the paleoseismologic data, clearly not a temporally steady process).

Although uncertainty regarding fault slip rates (i. e., tectonic loading rates) and the crude available age constraints on paleo-earthquakes within the LA region do not yet permit a rigorous statistical analysis, these observations add to a growing body of paleoseismological data which demonstrate that strain release is not a temporally and spatially random process. Such observations call into question Poissonian models of seismic hazard assessment.

Fault Branching

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Theoretical stress analysis for a propagating shear rupture suggests that the propensity of the rupture path to branch is determined by rupture speed and by the preexisting stress state. See Poliakov, Dmowska and Rice (*JGR*, submitted April 2001, URL below).

Deviatoric stresses near a mode II rupture tip are found to be much higher to both sides of the fault plane than directly ahead, when rupture speed becomes close to the Rayleigh speed. However, the actual pattern of predicted Coulomb failure on secondary faults is strongly dependent on the angle between the fault and the direction of maximum compression S_{max} in the pre-stress field. Steep S_{max} angles lead to more extensive failure on the extensional side, whereas shallow angles give comparable failure regions on both. Here we test such concepts against natural examples.

For crustal thrust faults we may assume that S_{max} is horizontal. Thus nucleation on a steeply dipping plane, like the 53° dip for the 1971 San Fernando earthquake, is consistent with rupture path kinking to the extensional side, as inferred. Nucleation on a shallow dip, like for the 12° -18° of the 1985 Kettleman Hills event, should activate both sides, as seems consistent with aftershock patterns.

Similarly, in a strike slip example, S_{max} is inferred to be at approximately 60° with the Johnson Valley fault where it branched to the extensional side onto the Landers-Kickapoo fault in the 1992 event, and this too is consistent. Further, geological examination of the activation of secondary fault features along the Johnson Valley fault and the Homestead Valley fault consistently shows that most activity occurs on the extensional side. Another strike-slip example is the Imperial Valley 1979 earthquake. The approximate S_{max} direction is north-south, at around 35° with the main fault, where it branched, on the extensional side, onto Brawley fault, again interpretable with the concepts developed.

Additional information: http://esag.harvard.edu/dmowska/PDR.pdf

Assessing Site and Path Effects by Full Waveform Modeling

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We have developed a method to calculate site and path effects for complex heterogeneous media using synthetic Green's functions. The Green's functions are calculated numerically by imposing body forces at the site of interest and then storing the reciprocal Green's functions along arbitrary finite-fault surfaces. By using reciprocal Green's functions, we can then simulate many source scenarios for those faults because the primary numerical calculations need be done only once. The advantage of the proposed method is shown by evaluation of the site and path effects for three sites in the vicinity of the Los Angeles basin using the Southern California Velocity Model (version 2.2).

In this study, we have simulated 300 realistic source scenarios for 5 major southern California faults and compared their responses at three sites. The effects of hypocenter location, the rupture speed, and slip function are tested in the scenarios. The results indicate that the variations in the peak velocity amplitudes and durations due to various source scenarios are as large as variations due to the heterogeneous velocity model.

Triggering of the 1999 Mw 7.1 Hector Mine earthquake by aftershocks of the 1992 Mw 7.3 Landers earthquake

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It has been widely suggested that the 1999 Mw 7.1 Hector Mine earthquake in the Mojave Desert, California, was triggered by the nearby 1992 Mw 7.3 Landers earthquake. If this is true, our simulations of the Landers earthquake aftershock sequence show that it is unlikely that the Landers earthquake triggered the Hector Mine earthquake directly. Rather we find that if such triggering did occur, there is an 85% chance that it happened because the Landers earthquake initiated a chain of smaller earthquakes that in turn delivered the critical stress to the Hector Mine earthquake hypocenter. We perform our simulations using the Monte Carlo method based on the Gutenberg-Richter relationship, Båth's Law, Omori's Law, and assumptions that all earthquakes, including aftershocks, are capable of producing aftershocks, and that each aftershock can be associated with a unique earlier earthquake which triggered it. In general our simulations show that if it has been more than several days since an M ? 7 California mainshock, most new aftershocks will be the result of secondary triggering. These aftershocks are not physically constrained to occur where the original mainshock increased stress. This may explain the significant fraction of aftershocks that have been found to occur in mainshock stress shadows in many static Coulomb stress triggering studies.

Paper submitted to JGR, August 2001. Preprints available at http://esag.harvard.edu/felzer/fbaer_aug01.pdf

RELM – A WORKING GROUP FOR THE DEVELOPMENT OF REGIONAL EARTHQUAKE LIKELIHOOD MODELS

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Previous working-group attempts to integrate seismic, geodetic, and geological information into a complete M≥6 earthquake forecast model for southern California have predicted seismicity rates near M 6.5 that exceed the historical rate by an approximate factor of two. Although an alternative "mutually consistent" seismic hazard source model has since been presented, several important issues remain unresolved and we are far from reaching consensus on how to construct such models. Toward solving this problem, a joint SCEC-USGS sponsored working group for the development of Regional Earthquake Likelihood Models (RELM) has been established. The goals are as follows: 1) To develop and test a *range* of viable earthquake-potential models for southern California (not just one "consensus" model); 2) To examine and compare the implications of each model with respect to probabilistic seismic-hazard estimates (which will not only quantify existing hazard uncertainties, but will also indicate how future research should be focused in order to reduce the uncertainties); and 3) To design and document conclusive tests of each model with respect to existing and future geophysical observations. The variety of models under development reflects the variety of geophysical constraints available; these include geological fault information, historical seismicity, geodetic observations, stress-transfer interactions, and foreshock/aftershock statistics. One reason for developing and testing a range of models is to evaluate the extent to which any one can be exported to another region where the options are more limited. The effort will include updating the geological fault database, the earthquake catalog, and the geodetic strain-rate map. We also plan to develop Java-based PSHA code in order to present the models as web-accessible applications with graphical user interfaces.

Accelerated Buildup of Stresses on the Southern San Andreas Fault and Surrounding Regions due to Post-Landers Viscous Flow

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The San Bernardino Mountain segment of the Southern San Andreas Fault has not ruptured in 190 years and is capable of producing major quakes with magnitudes greater than 7.5. We calculate that coseismic slips associated with the 1992 $M_w = 6.1$ Joshua Tree, $M_w = 7.3$ Landers, and $M_w = 6.3$ Big Bear quakes have raised Coulomb stress on the San Bernardino

Mountain segment by 1.5-2 bars. Using viscoelastic parameters that reproduce the observed post-Landers horizontal surface deformation, we calculate that viscoelastic flow in a lower crustal or upper mantle low-viscosity layer may have further added 1-1.5 bars of postseismic stress to the San Bernardino Mountain segment during 1992-2001, while the 1999 $M_w = 7.1$ Hector Mine quake added yet another 0.2-0.3 bars of coseismic stress. Most importantly, model calculations predict that viscoelastic flow will continuously add stresses to the San Bernardino Mountain segment for a couple of decades to come, with combined coseismic and postseismic stress changes approaching 3.5-5 bars from 1992 to year 2020. These accelerated stress accumulations may hasten the occurrence of a major earthquake on this part of the Southern San Andreas Fault. These results further imply that the Landers and Hector Mine quakes have generated a zone of increased stress that is predicted to migrate toward the Los Angeles Basin as the lower crust and upper mantle relax. Thus stress build-up is also predicted to occur on major portions of the San Jacinto and Elsinore faults in the years to come, bringing these fault zones closer to failure. To the north of the Landers region, near Barstow, viscous flow is calculated to increase stresses on the Calico fault. The San Jacinto and Calico faults may be showing signs of being close to rupture as numerous aftershocks continue to occur in these fault zones. This pattern of observed aftershock clustering and calculated Coulomb stress build-up is similar to that noticed in the Hector Mine region prior to the 1999 $M_w = 7.1$ quake.

Deep structure in the region of the San Fernando and Santa Clarita Valleys, southern California, from LARSE II seismic imaging, earthquake relocation, and magnetic modeling -- a progress report

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The Los Angeles Region Seismic Experiment has as its chief goal seismic imaging of sedimentary basins and faults in the Los Angeles region in order to address earthquake hazards posed by these geologic features. Two 150-km-long transects were investigated, one (LARSE I) crossing the Los Angeles basin and San Gabriel Mts in a northeasterly direction through the vicinity of the 1987 M 5.9 Whittier Narrows earthquake, and a second (LARSE II) crossing the San Fernando Valley (SFV) and Santa Clarita Valley (SCV) in a northerly direction through the vicinities of the 1994 M 6.7 Northridge and 1971 M 6.7 San Fernando earthquakes. Along the LARSE II profile, seismic reflection data and relocated earthquakes suggest that the Northridge fault is a relatively simple plane dipping ~30° southward from ~8 km depth beneath the Santa Susana Mts (between the SFV and SCV) to the 1994 hypocenter at ~19 km depth. Relocated hypocenters suggest a deep part of the Santa Susana fault was activated during the Northridge aftershock sequence. In contrast, the 1971 San Fernando earthquake appears to have activated several faults in addition to the two rupture planes inferred by Heaton (1982), including the

Northridge Hills blind thrust fault and a deep part of the San Gabriel fault. These two faults truncate reflections from the bottoms of the sedimentary basins in the SFV and SCV. We interpret the Northridge Hills blind thrust fault to truncate basin-bottom reflections beneath the SFV at ~5-6 km depth in the northern part of the SFV, and the San Gabriel fault to truncate similar reflections at ~3.5-4.5 km depth beneath the central part of the SCV. The San Gabriel fault projects to the 1971 hypocenter. In between the Northridge Hills blind thrust and San Gabriel faults, reflections are largely incoherent, and the velocity structure is complex.

Below the 1971 hypocenter (at ~13 km depth), the San Fernando fault appears to be contained in a broad north-dipping zone of reflectivity in which individual reflectors dip 25-35° northward. This zone intersects a broad south-dipping zone of reflectivity from the Mojave Desert approximately beneath the surface trace of the San Andreas fault. Reflectivity in the hanging walls of both the Northridge fault and the deeper part of the San Fernando fault (>13 km) is higher than in the footwalls.

The San Fernando fault structure is similar to structure imaged beneath the LARSE I profile, to the east, beneath the northern Los Angeles basin and the San Gabriel Mts, because a major range-bounding reverse fault connects northward to the San Andreas fault.

Timing of Large Earthquakes since A.D. 800 on the Mission Creek strand of the San Andreas Fault at Thousand Palms Oasis, Coachella Valley, California

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The Thousand Palms Oasis paleoseismic site is underlain by a series of six fluvial channels cut and filled since about A.D. 800. The southeast margin of a channel about 900 years old is offset about 2.5m giving a slip rate of approximately 2.8mm/yr. This low rate may not be representative of the Mission Creek fault as the site is located within a small step-over. We have exposed evidence for 4 and perhaps 5 large earthquakes since about 800 A.D. The 4 well-characterized events occurred about A.D. 830±60, 1230±60, 1505±50 and after a date with a range of A.D.1520-1680. The dates of the three youngest events lie within age ranges reported by Sieh (1986) for the Indio site. The most recent event at Thousand Palms is likely the A.D. 1676±35 event reported by Williams and Sieh (1990). A fourth event at Indio that occurred about A.D. 1020± 20 may be recorded at Thousand Palms Oasis but the evidence is less certain than for the other 4 events. Taken together, the two sites record 5 well-dated events on the San Andreas fault in the Coachella Valley. Each of these events strongly overlaps in time with an event at Wrightwood, suggesting that at least the southernmost 200 km of the fault may have ruptured in each of these 5 earthquakes. The average repeat time for large earthquakes on the San Andreas fault in the Coachella Valley is about 225 years, while the elapsed time since the most recent event is about 325 years.

Low Frictional Strength of Quartz Rocks at Subseismic Slip Rates

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Laboratory friction experiments on rocks at low sliding velocity yield typical values of the friction coefficient of 0.6-0.85. However, we find that an extraordinary degree of frictional weakening accompanies frictional sliding of 'room dry' quartz rocks at slip rates from 3 to 100 mm/s, faster than in most laboratory rock friction experiments, but slower that seismic slip rates. The experiments involve displacements of several meters, and have been done at normal stresses ranging from 5 MPa to 112 MPa. In some cases, the friction coefficient decreases from values obtained at lower speeds by more than a factor of 4; in the weakest cases the friction is as low as ~0.1. Calculations and measurements of temperatures demonstrate that this weakening is not caused by melting. Addition of water to the sliding surface causes an enhancement in weakening, whereas removal of intracrystalline water at 800° C and maintenance of a dry nitrogen environment during sliding results in a complete disappearance of the weakening mechanism. This profound effect of water suggests that weakening may result from lubrication via ultra-comminuted, shear-heated, wet amorphous material on the fault surface. At the cessation of rapid sliding, frictional strength increases to pre-rapid-sliding values with time, which may be caused by an amorphous-to-crystalline transformation, or increased polymerization of water-rich, gel-like material on the sliding surface.

Weakening occurs progressively with increased displacement, rapidly at first and then more gradually. However, this weakening only occurs at velocities over ~3 mm/s. We do not yet have a good description of the roles played by velocity and displacement and it is too early to offer a meaningful description of frictional resistance that could be used in earthquake models at seismic slip rates. However, the length scales over which the weakening occurs is often on the order of 0.5 m, and the decrease in friction after a few m of slip seems to be approximated by a straight line on a friction vs. log velocity plot, with a steep negative slope such that it trends down from ~0.6 at ~1 mm/s toward zero at ~0.3 m/s.

The Santa Barbara Seismic Array

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The Santa Barbara Seismic Array is an experiment that consists of an array of 12 PBIC seismic stations set up throughout Santa Barbara. The purpose of this experiment is to examine local seismic activity and to investigate how seismic waves are affected by the local geology of the Santa Barbara area. By conducting this experiment we will more accurately locate seismicity in the area as well as map the local amplification. Both will enable a better assessment of the damage potential and allow for a more refined hazard mitigation. Each of the 12 stations consists of a RefTek 72A-08 DAS, a one gigabyte disk, a GPS unit for timing, and a L4C-3D sensor. The array has been active since early August 2000. Data is collected and reviewed on a regular basis. Although the target area has not been seismically active, there have been several regional earthquakes recorded by at least one station from as far away as the Napa Valley. Most of the data has been false triggers due to environmental noise in this urban setting.

Drainage Diversion Produced by Active Folding: Santa Barbara Fold Belt, Santa Barbara, California

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Active growth of folds substantially influence the topographic development of the landscape. Tectonic processes of lateral and vertical fold growth directly produce relief in the form of linear hills and ridges with intervening basins. Drainages are commonly diverted on the upstream side of uplifting folds resulting in wind gaps, abandoned valleys, reversal of drainage flow directions, and anomalous, structurally controlled drainage patterns.

The Santa Barbara Fold Belt contains a series of roughly east-west active anticlines and synclines with several examples that demonstrate the influence of fold growth on landscape development. These include: 1) Sequential drainage diversions along laterally propagating folds that preserve a series of paleochannels produced as a result of stream abandonment, and were part of a distributary system that drained into a coastal lagoon and salt marsh, now the site of the City of Santa Barbara; 2) Alignment of channels parallel to fold scarps that divert south-flowing stream channels for several km; 3) Stream channels that flow across active folds at segment margins forming water gaps, preserving abandoned valleys and air gaps as evidence of former channel location; 4) Loss of headwater drainage and formation of drainage reversals as the result of fold growth, limb rotation, and subsequent coastal erosion; and 5) Production of linear valleys parallel to the coast that concentrate south-flowing drainages into synclinal basins, presently forming coastal sloughs and salt marshes.

Blind-thrust segmentation and fault-related fold kinematics of the Coalinga – Kettleman Hills – Lost Hills fold chain

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We investigate the nature of blind-thrust earthquake segmentation through the development of 3D geologic and geophysical models of the western San Joaquin basin fold-and-thrust belt of central California. The 1982 New Idria (Mw = 5.4), 1983 Coalinga (Mw = 6.5), and 1985 Kettleman Hills (Mw = 6.1) earthquakes occurred on three distinct segments of a blind-thrust system in the western basin. These earthquakes occurred beneath the New Idria, Coalinga, and Kettleman Hills anticlines, which are part of an en echelon fold system that extends south to Lost Hills. Previous subsurface and geodetic studies have demonstrated that these anticlines are fault-related folds that develop in response to motions on the blind-thrust system. The limits of the rupture areas for the three earthquakes are defined by distinct en echelon offsets of the fold system as indicated by surface geology. These fold offsets are thought to overlie geometric segment boundaries in the underlying blind-thrust fault, but the precise nature of the subsurface fault geometry remains unresolved. As recent studies on blind-thrusts in the Los Angeles basin have demonstrated, the geometric relationships between individual segments of a blind-thrust system play a significant role in the partitioning of slip and have a primary influence on seismic hazard assessment. Therefore, to better define these geometric segment boundaries, we construct comprehensive 3D models of the blind-thrust system that integrate more than 10,000 km of industry seismic reflection data, 200 well logs, surface geology, remote sensing data, and seismicity. In these structural models, kinematic indicators such as growth strata allow us to distinguish between competing models of fold growth and fault activity. The growth structures imaged in seismic data indicate that the kinematic development of the fold system varies considerably from north (Coalinga - Kettleman Hills) to south (Lost Hills). Moreover, the northern system of fault-related folds implies discrete fault segment boundaries that correspond to the patterns of seismicity; whereas, the southern system appears to be more continuous along the trend with less well defined segment boundaries and minimal seismic activity. The changes in fold segmentation style and earthquake activity also correspond to the position on the San Andreas fault, which lies 40 km to the west, where motion changes from locked to creeping. This may imply that variations in stress transfer from the San Andreas influence blind thrust segmentation and fold growth in the western San Joaquin basin.

Bilinear Source-Scaling Relations for M – log A Observations of Continental Earthquakes

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The Wells and Coppersmith (1994) M – log A data set (where M is moment magnitude and A is fault area; hereafter the WC94 data set) and the regression lines derived from it are widely used in seismic hazard analyses for estimating M, given A. These relations are

$$M = (0.98 \pm 0.03) \log A + (4.07 \pm 0.06), \tag{1}$$

the regression line for 148 earthquakes of all mechanism types (strike-slip, reverse, and normal; Table 2A and Figure 16a of WC94); and

$$M = (1.02 \pm 0.03) \log A + (3.98 \pm 0.07), \tag{2}$$

the regression line for 83 strike-slip earthquakes (Table 2A of WC94), where A has units of km^2. The regression lines (1) and (2) are well determined, as indicated by the small standard errors (± one sigma) for the regression coefficients. Because the coefficient of the log A term is essentially one, equations (1) and/or (2) are equivalent to constant stress-drop scaling, at least for $M \leq 7$ where most of the WC94 data lie. For $M > 7$, however, both relations increasingly underestimate the observations with increasing M.

We model the WC94 data set with constant stress-drop scaling ($\Delta\sigma = 30$ bars) for $M \leq 7$ and with L-model scaling (average fault slip $U = \alpha L$, where L is fault length and $\alpha = 2 \times 10^{-5}$) at larger M to obtain the relations

$$M = \log A + 4.03, \ A \leq 1000 \ km^2 \tag{3a}$$

and

$$M = 4/3 \log A + 3.03, \ A > 1000 \ km^2. \tag{3b}$$

Equations (3a) and (3b) fit the WC94 data set well in their respective ranges of validity, remarkably so in that there are no free model parameters in equations (3a) and (3b), although they do embody various model assumptions. Researchers and users of these and related data sets and models should take note of three significant issues associated with them. Because 0.2 units in M correspond to a factor of 2 in seismic moment, small differences in M can lead to large differences in earthquake rates in slip-rate-balanced calculations, such as WGCEP 1995 and 1999, with corresponding effects on earthquake probabilities and seismic hazard assessments. Second, modern seismological and geodetic data and methods allow fault area to be estimated in several different ways, with results that may or may not be consistent with the WC94 data set. Finally, the L-model employed here in equation (3b) and its concordance with the limited available data imply that earthquake stress drops increase with M for $M > 7$. This breakdown of similarity at $M \sim 7$ suggests that large earthquakes work differently from small earthquakes, as recently discussed by Kanamori and Heaton (2000).

A General Method for Quantifying the Effects of Stress Changes on Earthquake Probabilities

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Stress changes due to an earthquake can alter the probability of an earthquake on another fault by moving it towards or away from failure. I present a general technique for incorporating stress changes into earthquake probability estimates. The idea is to transform the pre-stress-change probability density function (pdf) for an earthquake of a given size in a given location into the post-stress-change pdf. The pre-stress-change pdf can be thought of as the density of a set of potential earthquake sources, each some time away from failure. The stress change moves each of these sources towards or away from failure by some amount of time. The time shift for each source is found using a rule which relates the post-stress-change time to failure of a fault to the pre-stress-change time to failure and the stress change. This rule should be based on some physical model of earthquake nucleation. Shifting each potential source shifts and deforms the density distribution, transforming it into the post-stress-change pdf. Previous methods used to compute changes in earthquake probability work similarly, but are tailored for specific fault failure models. The general method introduced here has the advantage that it can be used with any physical model of earthquake nucleation, and can therefore continue to be used as our knowledge of fault mechanics improves.

A 3D Spontaneous Rupture Model of the 1999 Izmit, Turkey Earthquake

Ruth A. Harris (USGS), James Dolan & Ross Hartleb (USC), Steve Day (SDSU)

We model the 1999 M7.4 Izmit, Turkey earthquake using a 3D finite-difference computer program that simulates earthquakes as spontaneous ruptures. We incorporate both the physics of earthquake rupture and the observed fault geometry and address two key questions: 1) What is the role of fault geometry in stopping earthquake ruptures? and 2) What is the state of stress on the faults?

(1) Theoretical studies of earthquake ruptures and geological observations have estimated how earthquakes might propagate on segmented faults. Both numerical simulations and geological observations suggested that 5 km might be the upper limit for coseismic jumps across stepovers if there were not any transfer faults [Harris and Day, 1993; 1999]. Alternatively, fault bends seem less likely to stop propagating earthquakes. Barka and Kadinsky-Cade [1988] showed that previous strike-slip earthquakes have propagated beyond bends of less than 30 degrees. The 1999 Izmit earthquake appears to have followed these expectations. This rupture did not jump across any stepover wider than 5 km, but did propagate beyond a 25 degree restraining bend. We simulate the Izmit earthquake and show how the earthquake propagated along the observed 3D fault geometry. We find agreement with the geologic, geodetic, and near-field seismological observations for most of the rupture, including possible supershear rupture velocities. We find it difficult to match the geologic surface slip observations at the eastern end of the rupture if the easternmost (Karadere) segment is vertical as inferred by the geologists. Instead it is possible that coseismic rupture of the Karadere segment was complicated by movement of or loading by a detachment surface in this region (e.g. Seeber et al.). A major conclusion of this study is the reminder that bends of less than 30 degrees may not impede large earthquakes. Therefore probability estimates based on the concept of fault segmentation should not use narrow bends to delimit strike-slip rupture lengths.

(2) We find that our simulated rupture is not able to propagate along the observed 3D fault geometry if the faults are at high stress levels. Instead, satisfactory replication of the actual rupture favors a low-stress fault scenario.

Reference: Harris, R.A., J.F. Dolan, R. Hartleb, and S.M. Day, The 1999 Izmit, Turkey earthquake - A 3D Dynamic Stress Transfer Model of Intra-earthquake Triggering, Bull. Seism. Soc. Am., in press.

The Stress-Change Relationship between the 1999 Hector Mine and 1992 Landers, CA Earthquakes

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Why did the 1999 Mw7.1 Hector Mine earthquake occur 7 years after and within 30 km of the Mw7.3 1992 Landers earthquake? A range of hypotheses has been presented to explain the relationship between the 2 large earthquakes in southern California. However, before embracing complex models of the possible tie between these 2 quakes, it behooves us to clarify our understanding of the more basic parameters. For example, what was the static stress change effect of Landers at the hypocenter of Hector Mine?

We use a simple model of dislocations in an elastic halfspace and calculate the Coulomb stress-change due to the 1992 Landers earthquake at the hypocenter of the 1999 Hector Mine earthquake. Because there is no consensus model of the Hector Mine hypocentral fault plane(s), we examine a range of possibilities for the hypocenter. For the Landers earthquake, we test a number of published slip models, including Wald and Heaton (BSSA, 1994) and Hudnut et al. (BSSA, 1994), in addition to Parsons and Dreger (GRL, 2000). We find that the Coulomb static stress change due to Landers at the Hector Mine hypocenter can vary by plus or minus 3 bars. The solution depends on the Landers model, on the record of earthquakes that occurred between Landers and Hector Mine and on the poorly resolved hypocentral depth of the Hector Mine earthquake. Our model is very simple and ignores known physical and temporal complexity in the region, such as material heterogeneity between the faults (e.g., Langenheim and Jachens, BSSA, in press) and pore-fluid flow. Therefore we caution other researchers who might be proposing that smaller stress changes caused by more complex, but less well understood phenomena (e.g. viscoelasticity, rate-and-state friction, delayed dynamic effects, etc.) triggered the Hector Mine earthquake.

Reference: Harris, R.A., and R.W. Simpson, The 1999 Mw7.1 Hector Mine, California earthquake - A test of the stress shadow hypothesis?, Bull. Seism. Soc. Am., in press.

Revisiting the 1971 Mw6.7 San Fernando Earthquake: Application of the Double Difference Method to Relocate the Aftershock Sequence

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We have relocated the 1971 Mw6.7 San Fernando mainshock and 1500 aftershocks using three different methods. Many of these aftershocks were recorded by a dense portable array deployed after the mainshock (Wesson et al. 1971). First, we use a one dimensional Vp and Vp/Vs model and relocated the sequence. Second, we relocate the sequence using the three-dimensional Vp and Vp/Vs models for southern California determined by Hauksson (2000). Third, we used the hypocenters determined with the 3-D models, as starting hypocenters to relocate the sequence using the double difference method. The double difference method shows the most improvement in the clustering of the hypocenters. These double difference hypocenters show two sub-parallel planes of aftershocks that dip at about 45° to 55° to the northeast and extend from about 5 km depth down to depth of 14 km (the depth of the mainshock hypocenter). From the surface and down to 5 km depth the dip is shallower or about 20° to 25°. The double difference hypocenters support the initial interpretations by Whitcomb et al. (1973) and also support the idea of two sub-parallel rupture planes suggested by Heaton (1982). The southwest striking Chatsworth trend of aftershocks that was identified by Whitcomb et al. (1973), remains the most prominent part of this aftershock sequence consisting of many sub-parallel clusters.

Caltech-USGS Element of TriNet: Modern, Digital Multi-Functional Real-time Seismic Network for Southern California

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Caltech and USGS Pasadena Office are nearing completion of building of the Caltech/USGS Element of TriNet. TriNet already records and analyzes earthquake ground motions, and distributes that information quickly, to improve our understanding of earthquakes and their effects, to contribute to improving building codes and structural design, and to facilitate emergency response in cooperation with other agencies. We report on new technologies, approaches and new products in part developed and implemented by the SCSN/TriNet. Already 135 out of 150 planned broadband and strong motion stations have been deployed and connected with IP networking to the central site. The TriNet real-time systems and database have been operating online for more than a year, processing real-time data from more than 370 stations, or 1400 high sample rate data channels. These capabilities were tested in the 1999 Mw7.1 Hector Mine earthquake. Implementation of new post-processing and catalog generation approaches is currently underway.

A Benchmarking Study of Three-Dimensional, Viscoelastic Deformation Modeling Codes

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Several numerical codes are currently being used by members of the SCEC community to model three-dimensional, viscoelastic deformation of the Earth's crust and upper mantle. A common application of such codes is to model the evolution of surface velocities and crustal stresses due to viscoelastic relaxation of the lower crust or upper mantle following large earthquakes. This modeling is central to studies of seismic hazard and earthquake triggering, and to inversions of postseismic surface displacements for rheology of the mantle and/or lower crust.

As far as we know, no formal benchmarking studies comparing the performance of these codes has been done. Benchmarking studies are important for several reasons, most obviously because we should insure the numerical codes can reproduce available analytical solutions. Where analytical solutions are not available, these codes should give comparable results that converge to a common solution as smaller time steps and nodal spacing intervals (or more spherical harmonic modes) are used.

We will compare the performance of the finite-element codes GAEA (Saucier and Humphreys, 1993) and TEKTON (Melosh and Raefsky, 1981), and the semi-analytical code VISCO1D (Pollitz, 1997) at modeling surface displacements and crustal stresses resulting from strike-slip faulting. Other codes may also be included in the comparison. The fault will be modeled as a vertical planar surface with uniform slip, which fully penetrates the elastic upper crust. The lower crust will be modeled as a Maxwell viscoelastic layer. Both two- and three-dimensional faulting models will be developed and evaluated. We will compare the modeled coseismic stresses and displacements with an Okada dislocation solution. Postseismic displacements and stresses from several time intervals will be compared with each other and, where possible, with analytical solutions. We will address how small time steps and nodal spacing must be for the finite-element codes to accurately calculate stresses and displacements over various spatial and temporal scales. We will also show graphically how each code's solution errors are spatially distributed.

Analysis of Amplitudes from the Los Angeles Basin Passive Seismic Experiment (LABPSE)

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LABPSE was a dense seismic array stretching northeast to southwest across the LA Basin with seismographs spaced approximately 10km apart running from the edge of the San Gabriel Mountains to Seal Beach. The 18 stations making up the array ran from March to November of 1997. We present a preliminary amplitude analysis of data from LABPSE.

More than 2000 events were recorded and catalogued during the experiment. 80 of those events were strong enough to provide seismograms with good signal to noise ratios. These range in magnitude from 2 to 5.3. The maximum amplitudes from P waves are picked within a +/-2 second window around the first arrival. The maximum S wave amplitudes are found within a +/-3 second window. The amplitudes are corrected for geometrical spreading and attenuation assuming an isotropic and homogenous medium. 51 of the events are corrected for fault plane radiation patterns.

Stations in the northeast, at the edge of the San Gabriel Mountains, produced the smallest amplitudes as expected over thick bedrock. Amplitudes increase from the San Gabriel Mountains to the Puente Hills. Amplitudes to the North and South of the Puente Hills appear to be magnified suggesting a deep basin structure. Amplitudes increase through the basin and lower towards Seal Beach. However, the amplitudes are still quite large at stations near the coast. This suggests that the sedimentary layer in the basin extends off the coast at Seal Beach and may be quite thick.

Does Apparent Stress Vary With Earthquake Size? Possible Mechanism of Artificial Size Dependency

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The energy radiated from the seismic source (Es) has been estimated for a wide range of earthquake sizes. Many studies have found that the ratio between Es and seismic moment (apparent stress) increases as seismic moment increases. Es is distributed across a wide frequency band, reliable estimates require broadband recordings relative to the corner frequency. There are several possible mechanisms that could bias estimates of Es: 1) data bandwidth is too narrow, 2) a constant upper cutoff on the corner frequency affects event selection, and 3) unmodeled elastic/anelastic wave propagation effects may obscure source properties. We can attempt to account for 1) by estimating the missing energy based on the assumption of an omega-square spectral model. For 2) we know the minimum energy of missing events and can show where these events should be located in the moment-apparent stress relation. These two factors act to diminish the size dependency of apparent stress suggested by previous studies.

For 3), we re-examined the data of Prejean and Ellsworth (2001) from a 2-km deep borehole in Long Valley Caldera, California. First, assuming an omega-square model with a constant Q, we determined the stress drop and apparent stress of 41 events ($0.5 < Mw < 5.0$). We find that some small events have small apparent stresses of about 0.003-0.03 MPa, and also find that these events have low stress drops of 0.01 to 0.1 MPa. Most larger events have both larger stress drops of 1-10 MPa and larger apparent stresses. This analysis supports the decline of Es with declining moment. It is natural that stress drop would have a strong relationship to the apparent stress---we find (apparent stress) = 0.3 x (stress drop)---since we assumed an omega-square model. Insofar as no systematic change in the spectral shape is observed with seismic moment in the data, it is unlikely that stress drop and apparent stress will have different dependencies on seismic moment. We also estimated stress drops using spectral amplitude ratios for 14 co-located events ($1 < Mw < 3$). In this case we assumed an omega-square model, but relied on spectral ratios to eliminate the effects of attenuation. Corner frequencies measured from the spectral ratios are significantly higher for small events than before and follow constant stress drop and constant apparent stress scaling. These contradictory results arise from the different assumptions about attenuation and spectral shape. They demonstrate how a constant Q assumption can introduce an artificial size dependence in apparent stress. The observations can be reconciled if Q decreases with increasing frequency above 25 Hz and/or if there are site effects around 10 Hz.

In conclusion, size dependent scaling of Es may result from artifacts. Variations in the efficiency of seismic energy radiation over the entire observable range of earthquake size may not yet be resolved.

Numerical Simulations of Fault Zone Guided Waves: Accuracy and 3-D Effects

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In the last decade fault zone (FZ) guided head and trapped waves have been observed along several earthquake faults with receivers close to the FZ. There is hope that analysis of such phases may be used to provide a higher resolution imaging of FZ structure at depth than is possible with standard ray tomographic methods. Observed FZ guided waves can be well explained and interpreted with inversion algorithms based on simplified 2D plane-parallel FZ structures (e.g., Michael and Ben-Zion, 2001; Peng et al., 2001). This is, perhaps, not surprising since an ideal seismic wave guide is 2D and thus FZ waves will not exist in structures that are too heterogeneous to be approximated, over a given spatial extent and observed frequencies, as 2D. However, the interpretation of seismic FZ guided waves is highly non-unique. Ben-Zion (1998) performed a parameter space study for FZ waves in 2D structures aiming to clarify the effects of, and trade-offs between, propagation distance along the fault, FZ width, velocity contrast across the fault, attenuation coefficient of FZ material, normal offsets of source and receivers from the FZ, and receiver depth. All these variables were shown to have significant effects on FZ guided waves, and thus all are important degrees of freedom in inversions of observed FZ waves.

Here we use 3D finite-difference calculations to perform a parameter-space study of waves in various cases of modestly irregular fault zone structures. We investigate the accuracy of the 3D numerical solutions for sources at material interfaces and discuss some dominant effects of 3D structures. We also show that simple mathematical operations on 2D solutions generated with line sources allow accurate modeling of 3D wave-propagation produced by point sources. The simulations indicate that structural discontinuities of the fault zone (e.g. fault offsets) larger than the FZ width affect significantly the trapping efficiency. On the other hand, vertical property gradients, FZ narrowing with depth, small-scale scatterers, and moderate geometrical variations have small effects on the waves and are not significant degrees of freedom. Various other cases (e.g., a surface layer and heterogeneities with correlation length ≈ FZ width) fall on a middle ground and have modest effects on the waves. The results also show that sources located with appropriate orientations outside and below a shallow FZ layer can produce considerable guided wave energy in the overlying fault zone layer.

Aftershock Zone Scaling

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We investigate the distribution of aftershock zones for large earthquakes(scalar seismic moment $M >= 10^{19.5}$ Nm, moment magnitude, m >= 7). Mainshocks are selected from the Harvard CMT catalog and aftershocks from the PDE (NEIC) catalog. The aftershock epicenter maps are approximated by a two-dimensional Gaussian distribution; the major ellipse axis is taken as a quantitative measure of the mainshock focal zone size. The dependence of zone length, l, on earthquake size is studied for three representative focal mechanisms: thrust, normal, and strike-slip. Although the numbers of mainshocks available for analysis are limited (maximum a few tens of events in each case), all earthquakes show the same scaling ($M \sim L^3$). No observable scaling break or saturation occurs for the largest earthquakes ($M >= 10^{21}$ Nm, m >= 8). Therefore, it seems that earthquake geometrical focal zone parameters are self-similar.

Modern Californian Earthquake Catalogs, Their Comparison

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In an effort to create a combined earthquake catalog for Southern California, we analyze several earthquake catalogs compiled in California since the 1970s in order to determine the accuracy of their magnitude determination and earthquake focal mechanisms. The Caltech, Harvard CMT, and USGS moment tensor catalogs, two catalogs (northern and southern Californian) of focal mechanisms solutions, based on the HYPO71 program, as well as two catalogs of regional moment tensor inversion (from UC Berkeley and Caltech) are compared. We investigate the differences in magnitude estimates in these catalogs and focal mechanism orientation uncertainty for earthquakes with magnitude 4.7 and higher. We define the focal mechanism discrepancy by determining the smallest 3-D rotation angle needed to transform one double-couple mechanism into another. Only several tens of earthquakes can usually be correlated in different catalogs, thus the measurement reliability is relatively low. However, using pairwise differences between the catalogs we evaluate the magnitude uncertainties (standard deviations) as about 0.19, 0.08, 0.09, 0.22, 0.19, 0.08, and 0.09 for the listed catalogs, respectively. The average rotation angle is approximately 18, 18, 38, 33, 18, 20 degrees, for the last six catalogs in the list, respectively. We note that the focal mechanism accuracy for the first motion observations (HYPO71 solutions) is low, since the quoted angles are comparable with the average angle obtained for the random rotation of a double-couple source: it is 76 degrees.

Accessing Waveform Data from the Southern California Earthquake Data Center (SCEDC)

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With TriNet assuming the role of southern California's earthquake monitoring network at the beginning of this year, the SCEDC has shifted from a custom-built database to an Oracle database system. Now, in addition to archiving triggered waveform data, the SCEDC archives continuous waveforms (20 samples per second or less) for over 150 broadband stations. Metadata such as hypocenters, magnitudes, amplitudes, and pointers to waveform archives are also stored in the Oracle relational database. Temporary archives of incoming waveform data are maintained on twin Sun 450 database servers. Permanent archives are written to a 5-terabyte mass storage system. Since a single database system spans both TriNet and SCEDC, new earthquake data are available to the seismological community in near real-time.

Primary access to the database and waveforms is through the Seismogram Transfer Program (STP) interface. The interface enables users to search the database for earthquake information, phase picks, and continuous and triggered waveform data. Output is available in SAC, miniSEED, and other formats. Users may create custom search profiles that are retained between STP sessions. A simple client version of STP, downloadable from http://www.scecdc.scec.org/software.html, places data directly onto the user's disk as they are retrieved. A second, Web-based version of the interface can be accessed at http://www.scecdc.scec.org/stp.html; it collects selected waveforms into a tar file that the user can subsequently transfer to a local computer via ftp.

Effects of Pre-Stress State and Propagation Velocity on Dynamic Fault Branching

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Major earthquakes seldom rupture along single planar faults. Instead there exist geometric complexities, including fault bends, branches and stepovers, which affect the rupture process, including nucleation and arrest. Here we consider a mode II rupture which propagates along a planar fault and encounters an intersection with a branching fault that makes an angle with the main fault.

Analyses based on elastic stress fields near propagating ruptures suggest that whether a branch path will be followed or not, and whether branching to the extensional or compressional side is favored, depend on both the rupture propagation velocity as the branch is approached and on the pre-stress state before rupture arrives. See Kame and Yamashita (GJI, 139, 345-358, 1999) and Poliakov, Dmowska and Rice (JGR subm. 2001, http://esag.harvard.edu/dmowska/PDR.pdf). The latter predicted that branching to the extensional side would be favored in all pre-stress states except for those in which the direction of maximum pre-compression S_{max} makes a shallow angle Δ with the fault plane. Angles $\Delta < 45°$ result when the ratio S^o_{xx}/ S^o_{yy}, of fault parallel to fault normal pre-stress, is greater than unity, and angles $\Delta > 45°$ result when the ratio is less than unity. Thus it is anticipated that the most favored side for rupture branching should switch from the extensional to the compressive side as we consider progressively larger S^o_{xx}/ S^o_{yy} (which means progressively smaller Δ).

In order to test that and other predictions, we have adapted the elastodynamic boundary integral equation methodology of Kame and Yamashita to 2-dimensional Mode II ruptures along branched fault systems, to allow simulations of rupture in which the failure path is dynamically self-chosen. Failure in the modeling is described by a slip-weakening law for which the peak and residual strength, and strength at any particular amount of slip, is proportional to normal stress ($-S_{nn}$). Our current results are preliminary. Nevertheless, by comparing results for $S^o_{xx}/S^o_{yy} = 0.8$ with those for 1.4, we have established, e.g., that a 15° fault branch to the extensional side, which the rupture chose to follow in all simulations with the smaller pre-stress ratio (0.8), was never chosen (i.e., the rupture stayed on the main fault) in simulations with the higher ratio (1.4), verifying the theoretical concepts. In simulations for which the friction properties of the branch are the same as for the main fault, we find that with the lower pre-stress ratio, the branch is followed at all velocities of rupture approach. However, we expect the branch to be followed only at relatively high rupture velocities, approaching the Rayleigh speed, when the main fault has reduced friction compared to the branch. That concept will be tested in continuing simulations.

Oak Ridge-Mid Channel Anticline (ORMCA), Santa Barbara Channel

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The most western sector of ORMCA is an actively growing anticline with pristine fold scarps, fault scarps, and cross faults that segment the structure. A prominent fault scarp is associated with the Mid Channel fault, a steeply north dipping structure in the hanging wall of the south dipping Oak Ridge fault. Seismic reflection data linking surface and sub-surface features, indicates that the vertical rate of deformation, due to faulting is approximately 0.5m/ky. The rate of vertical deformation produced by folding is about 2m/ky.

The crest of ORMCA is marked by several surface pits ranging from ~ 100 to 200 meters in diameter. These are assumed to be gas emission pits. Stable isotopic data of foraminifera from four push cores taken near the crest of ORMCA suggests the influence of isotopically light methane in the sediments and water column. The planktonic foraminifera assemblages in a gas-emission pit indicate glacial age of surface sediments, with deposition during a sea level low stand. This may suggest the age of formation of he pit. A single 14-C date on foraminifera suggests one pit may be about 11ka.Also present on ORMCA are conspicuous features of unknown origin. They are about the same size as the gas emission pits, but are positive features that may be tar or mud mounds.

Results from the SCIGN Analysis Committee

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1 U. S. Geological Survey, Pasadena
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The Southern California Integrated GPS Network (SCIGN) Analysis Committee has worked since 1998 to compare GIPSY-OASIS II solutions from the Jet Propulsion Laboratory (JPL) and GAMIT/GLOBK/GLORG solutions from the Scripps Institution of Oceanography (SIO). In earlier comparisons of JPL and SIO results, we found discrepancies of several mm in station position and several mm/yr in station velocity and traced these differences to inconsistent antenna heights, different methods of time series analysis, and different reference frames.

We defined a preliminary SCIGN reference frame (SCIGN97 v.1.) by choosing 16 regional stations with good geographic distribution and a fairly complete time history back to 1996. JPL and SIO reprocessed data from these stations, with loose constraints on station coordinates. The committee used GLOBK/GLORG to combine the JPL and SIO daily solution and covariance files, aligning to the IGS97 positions of global stations. For data back to 1996, the mean difference between JPL and SIO solutions in this reference frame is typically less than 1 mm in the north and east coordinates and 1 to 3 mm in the vertical coordinate.

For baselines, which do not depend on reference frame, the mean difference in JPL and SIO relative position is about 0.1 mm in the horizontal and 0.5 mm in the vertical. Proportional error in baselines is 0.9, 2.5, and 1.0 parts per billion (ppb) for the north, east, and vertical components, respectively, and 1.2 ppb for baseline length.

Analysis of data from the PANGA array suggests that the most appropriate error model for data from permanent GPS stations is a combination of white and flicker noise level, where the flicker noise is 40% of the white noise level. The best estimate for the error is 1.5, 2.5, and 5.0 mm of white noise in north, east, and vertical components, respectively, and 0.6, 1.0, and 2.0 mm of flicker noise. With this error model, the standard error in offset estimation is about 0.5 mm in the north, 1 mm in the east, and 2 mm in the vertical.

Irregularities in Early Seismic Rupture Propagation for Large Events in a Crustal Earthquake Model

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We study early seismic propagation of model earthquakes in a 2-D model of a vertical strike-slip fault with depth-variable rate and state friction properties. Our model earthquakes are obtained in fully dynamic simulations of sequences of instabilities on a fault subjected to realistically slow tectonic loading (Lapusta et al., JGR, 2000). This work is motivated by results of Ellsworth and Beroza (Science, 1995), who observe that for many earthquakes, far-field velocity seismograms during initial stages of dynamic rupture propagation have irregular fluctuations which constitute a "seismic nucleation phase".

In our simulations, we find that such irregularities in velocity seismograms can be caused by two factors: (1) rupture propagation over regions of stress concentrations and (2) partial arrest of rupture in neighboring creeping regions. As rupture approaches a region of stress concentration, it sees increasing background stress and its moment acceleration (to which velocity seismographs in the far field are proportional) increases. After the peak in stress concentration, the rupture sees decreasing background stress and moment acceleration decreases. Hence a fluctuation in moment acceleration is created. If rupture starts sufficiently far from a creeping region, then partial arrest of rupture in the creeping region causes a decrease in moment acceleration. As the other parts of rupture continue to develop, moment acceleration then starts to grow again, and a fluctuation again results. Other factors may cause the irregularities in moment acceleration, e.g., phenomena such as branching and/or intermittent rupture propagation (Poliakov et al., submitted to JGR, 2001) which we have not studied here.

Regions of stress concentration are created in our model by arrest of previous smaller events as well as by interactions with creeping regions. One such region is deep in the fault zone, and is caused by the temperature-induced transition from seismogenic to creeping behavior at depth. Small events appear in our model at that transition as we decrease the characteristic slip distance for evolution of frictional strength (but not if that distance is unrealistically large). Such clustering of small events at transitions from seismogenic to creeping behavior seems to occur on real faults as well, as we show in examples. To compute moment acceleration that can be compared with data, we translate the results of our 2-D fault model to a 3-D model with essentially radial symmetry on the fault plane. We will discuss limitations of that interpretation; in particular, it may overestimate the effect of partial arrest of rupture in creeping regions.

Our present work cannot resolve whether there are any differences in the early phases of seismic moment release, i.e. in the seismic nucleation phase, that would make the beginning of larger events look different from smaller ones that are about to arrest. We have shown that the aseismic nucleation phase and the earliest phases of dynamic breakout are virtually identical for small and large events in our simulations. If early moment release is mostly affected by stress heterogeneities left by previous small events and by creep processes, as our present study suggests, then any such differences would have to be related to as yet unidentified properties of the pre-stress field that might determine the ultimate event size.

See http://esag.harvard.edu/lapusta/Lapusta_Rice_Jun01.pdf, submitted to JGR, 2001.

Modeling of nonlinearity in strong ground motion during the 1994 Northridge, earthquake

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SCEC sponsored studies and strong motion data recorded during the 17 January 1994 Northridge earthquake ($M_{\_}$ 6.7) have been used to determine the presence of nonlinear effects in strong ground motion. The data available included borehole velocity profiles, weak to strong motion records, and dynamic soil laboratory tests. Several sedimentary stations have responded with sharp resonance peaks. Signals recorded at these sites are good candidates to investigate nonlinear effects. Measurements of ground motion observed at the bedrock site Jensen Generator Building (JGB) have been coupled with the nonlinear model to generate scenarios of ground shaking at the Jensen Main Building (JMB) site. While measurements of ground motion observed at the bedrock site Pacoima Dam Downstream (PCD or PAC), have been coupled with the nonlinear model to generate scenarios of ground shaking at the Newhall Fire Station (NWH) site.

The nonlinear soil model used in this study includes effects such as anelasticity, hysteretic behavior —also known as the memory effect— and cyclic degradation due to pore water pressure. Two situations have been investigated, one that includes the effect of pore pressure (effective stress analysis) and the second without it (total stress analysis). In the first case, the nonlinear model propagated a signal through layers of saturated material; whereas only layers of dry materials are used in the second case. Many scenarios of nonlinear ground shaking have been computed. All the accelerograms were computed up to a maximum frequency of 10 Hz. Using trial-and-error modeling and comparison with the observed time history, we were able to refine the synthetic accelerograms.

The results of the numerical experiments conducted at these sites support the assumption that a nonlinear effect contributes significantly to the ground shaking observed at the surface. Pore pressure cyclic mobility contributes significantly to the ground shaking observed at the surface of the JMB site. A characteristic feature of simulations including pore pressure effects is the depletion of the high frequency in the signal in good agreement with both the recorded and synthetic accelerations. However contrary to the results obtained for the JMB site, it is not clear that that pore pressure plays a significant part in the recorded accelerograms at the NWH site. We have to stress that in this study, conclusive finding of nonlinearity is based on direct simulations of nonlinear soil dynamics and the quantification of the nonlinearity in terms of the model parameters. Of the two contentious interpretations proposed to explain the recorded motions at sedimentary sites during the 1994 Northridge earthquake—that is, nonlinear effect by Field et al., (1997) and several others versus the scattering of waves in the upper kilometers of the earth's crust by O'Connell (1999)—only the first one is supported by the results presented in this study.

Field, H. E., P. A. Johnson, I. A. Beresnev and Y. Zeng, Nonlinear ground-motion amplification by sediments during the 1994 Northridge earthquake, *Nature*, **390**, 599-602, 1997.

O'Connell, D. R. H., Replication of apparent nonlinear seismic response with linear wave propagation models, *Science* **283**, 2045-2033, 1999.

Tsunami Potential of Major Restraining Bends along Submarine Strike-Slip Faults

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Strike-slip faults are often considered unlikely to generate destructive tsunamis due to the general horizontal fault movement. Real strike-slip faults, however, are sinuous with many curves and offsets of the fault trace so that local areas of uplift or subsidence occur. At restraining bends or fault offsets, where the lateral slip is impeded, uplift occurs. Major restraining bends involve oblique fault segment lengths exceeding 10 kilometers, and the area of uplift exceeds100 square kilometers. For submarine restraining bends, sudden seafloor uplift during large earthquakes are likely to generate substantial tsunami, which may be locally destructive along adjacent coastlines. We are investigating a major restraining bend along the San Clemente fault zone offshore of southern California to determine its potential for generating tsunamis that may be destructive to nearby San Diego and northern Baja California cities (Tijuana and Ensenada). The 15 degree oblique fault segment is about 60+ km, which may rupture during an earthquake of M~7 depending on fault displacement. The area of seafloor uplift, as observed from high-resolution SeaBeam bathymetry, is about 875 square kilometers. The maximum uplift, measured as total seafloor relief, is about 430 meters, although the total tectonic uplift determined from high-resolution seismic reflection profiles is about 720 meters. Mapped seafloor bathymetry, to determine relative uplift and scaled for a reasonable earthquake (single-event) displacement, is used to calibrate elastic dislocation models for potential tsunamigenic earthquake source deformation. Hydrodynamic models developed at USC are then applied to propagate the tsunami to the adjacent San Diego/northern Baja California coastline to estimate run-up potential. We find that previous elastic dislocation models used to estimate tsunami potential in southern California tend to underestimate the seafloor displacement, compared to observed faulting during recent large (M>7) onshore earthquakes and seafloor fault scarps (1-3 meters high) viewed during submersible dives in the area. With many large restraining bends on numerous offshore fault zones, the risk for local earthquake generated tsunami in the southern California offshore region is greater than previously stated.

Spatio-temporal Patterns of In-elastic Strain Produced by Southern California Earthquakes

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We analyze spatial and temporal features of co-seismic in-elastic deformation in the southern California crust. At present we examine results associated with approximately 100,000 earthquakes occurring between 1981 and 2000, and are in the process of expanding the research to include earlier events. Locations and fault plane solutions for the earthquakes are determined using the HYPOINVERSE and FPFIT computer codes. From the fault plane solutions and event magnitudes we calculate the potency tensors of the earthquakes, where the potency is the integral of the inelastic co-seismic strain over the deforming volume. Division by the involved rock volume would yield the strain tensors describing the co-seismic deformation. However, those rock volumes are not well constrained so we work with potency. Since the potency and strain tensors are proportional to each other, their principle axes have the same orientations and relative magnitudes.

The data are spatially and temporally binned, and summed in each bin to yield the cumulative potency tensors for given sub-regions and time periods. The eigenvectors and eigenvalues of the tensors are calculated, giving the orientation of the principle potency (and strain) axes. By comparing the plunges of the three axes, we estimate the expected style of faulting for each cumulative tensor. We compare the patterns of potency and faulting style at scales ranging from 2.5 km^2 columns of crust to all of southern California. We also examine changes in the pattern across year-long sub-catalogs covering the entire analyzed time period. Other examined features include (1) the relative prevalence and location of different faulting styles, (2) the percentage of bins with principle potency/strain axes that are significantly rotated out of the horizontal and vertical planes, and (3) the spatial correlation lengths of the orientation and magnitude of the potency tensors. Spatio-temporal patterns of these features and their relations to local fault geometry and large earthquake histories will be discussed in the meeting.

Healing of the Landers Rupture Zone from 1994-2000 after the 1992 *M*7.4 Earthquake

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We conducted seismic surveys using near-surface explosions at the Johnson Valley fault (the southern Landers rupture segment) in 1994, 1996, and 1998. We found that the shear velocity within the rupture zone increased by ~1.2% between 1994 and 1996, and increased further by ~0.7% between 1996 and 1998 as opposed to less changes in surrounding rock sides. This trend indicates the Landers rupture zone has been healing by strengthening after the mainshock, most likely due to the closure of cracks that opened during the 1992 earthquake. The closure of cracks increases the frictional strength of the fault zone, as well as its stiffness. The observed fault-zone strength recovery is consistent with a decrease of ~0.03 in the apparent crack density within the fault zone. The ratio of decrease in travel time for *P* to *S* waves changed from 0.75 in the earlier two years to 0.65 in the later two years between 1994 and 1998, suggesting that cracks near the fault zone are partially fluid-filled and have became more fluid saturated with time. The healing rate decreased with time and also varied along the rupture zone with a relatively large change near the dilational fault stepover as compared to the nucleation zone where the simple rupture is presumed, probably related to the stress-controlled fluid redistribution around the fault stepover [*Peltzer et al.*, 1998]. However, the data from the experiment in 2000 showed that seismic velocities at the Landers rupture zone did not increase further more but with a slight decrease in shear velocity between 1998 and 2000. While we can not rule out the possibility that the fault healing at Landers has become invisible since 6 to 8 years after the 1992 earthquake, we speculate that the healing process on the Landers rupture zone might have been affected by the *M*7.1 Hector Mine earthquake on October 25, 1999, which occurred only ~25 km east of the Landers rupture zone. It triggered slips on the neighboring faults [*Sandwell et al.*, 2000; Agnew, 2000] and could cause crack opening or coalescence in the shallow crust due to strong shaking or change in the mean stress from the Hector Mine mainshock. Such phenomena has been reported for the 1989 Loma Prieta earthquake by *Dodge and Beroza* [1997].

Multiple-Fault Rupture of the *M*7.1 Hector Mine, California, Earthquake from Fault-Zone Trapped Waves Generated by Explosions and Aftershocks

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We carried out an experiment using 3 tight linear seismic arrays deployed across the rupture zone of the 1999 *M*7.1 Hector Mine earthquake to record fault-zone trapped waves generated by explosions and aftershocks within the rupture zone. We studied the complex multiple-faulting pattern of the 40-km-long rupture zone with trapped waves. 3-D finite-difference simulations of fault-zone trapped waves indicate a 75 to 100-m-wide low-velocity and low-*Q* zone (waveguide) along the rupture surface on the Lavic Lake fault (LLF) in the Bullion Mountains. The *S* velocity within the waveguide varies from 1.0 to 2.5 km/s at depths of 0-10 km, reduced by ~40-50% from the wall-rock velocity, and *Q* is ~10-60. The pattern of aftershocks for which we observed trapped waves shows that this low-velocity waveguide has two branches in the northern and southern portions of the rupture zone, indicating a multiple-fault rupture at seismogenic depth. North of the Bullion Mountains, although only the rupture segment on the northwest LLF broke to the surface, a rupture segment on a buried fault also extended ~15 km in the more northerly direction from the mainshock epicenter. To south, the rupture on the LLF intersected the Bullion fault and bifurcated while there was minor rupture on the southeast BF, which dips to northeast and disconnects from the LLF at depth. Thus, the analysis of fault-zone trapped waves helps delineate a more complex set of rupture planes than the surface breakage, in accord with the complex pattern of aftershock distribution [*Hauksson et al.*, 2000] and geodetic evidence [*Chen et al.*, 1999; *Dreger et al.*, 2000; *Simons et al.*, 2000]. that the Hector Mine event involved several faults which may also rupture individually. Simulations of dynamic rupture using a finite-element code show that generic models are able to produce the general features of the northern part of the rupture, including slips on sub-parallel fault segments. The models indicate that such a faulting pattern is physically plausible and consistent with observations. We shall repeat the explosions in the Fall of 2001 to monitor temporal changes in physical properties near the rupture zone.

The Prediction of Near-Source Strong Ground Motion from the 1999 M7.7 Chi-Chi, Taiwan Earthquake

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We predicted strong ground motions in the source area of the 1999 Chi-Chi earthquake using a 3D viscoelastic finite-difference (FD) method and a 3D velocity structure model (Chen et a., JGR, 1998). The source process used for the prediction is determined through the inversion of near-source ground motion using 3D Green's functions. We assume single plane, finite fault. The data from 22 three-component stations are inverted for the source parameters of 200 subfaults. Both the data and Green's functions are band-passed between 0.05–0.5 Hz. A global hybrid search algorithm is employed to solve for the two components of fault slip, rise time, rupture time and the shape of source function for each subfault. In the inversion process we limit the time window to the direct P and S waves to mitigate the influence of the uncertainties in the 3D-velocity structure on later arrivals.

We computed the three-component near-source ground motions generated by the inverted source model at another 30 stations. Some of these stations are located very near the rupture surface. The predicted velocities are compared with the recorded ground motions in the frequency band of 0.05–0.5 Hz. A good fit between observed waveforms and the synthetics is achieved. To quantify the fit between observations and synthetics we use an objective function that is a trade off between cross correlation and the L2 norm (Sen and Stoffa, 1991). Based on this objective function we get an average fit of 0.59 for the 22 stations used in the inversion and an average fit of 0.40 for 30 stations in the prediction.

Visco-Elastic Damage Rheology Model: Theory and Experimental Verification

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We present a visco-elastic damage rheology model to describe evolving elastic properties and accumulation of irreversible deformation under large strain. Following the damage rheology model of Lyakhovsky et al. [JGR, 1997], we add a third parameter γ to the parameters of linear Hookean elasticity λ and μ to account for the asymmetry of the response of rocks for loading under tension and compression conditions. These three parameters define the effective instantaneous elastic properties of rock and they are functions of an evolving damage state variable α. We also introduce an effective viscosity proportional to the time derivative of α (i.e., the rate of damage change) to account for gradual accumulation of irreversible deformation due to slip of evolving micro-cracks. We use six deformation experiments carried out at the USGS Rock Mechanics laboratory, Menlo Park, with different rock samples and confining pressures to provide experimental verification for the above visco-elastic damage rheology model. The analysis of data from the experiments employs the observed stresses and acoustic emissions as inputs, while the observed strains are compared with model predications. The latter are calculated with a procedure designed to invert the relations between the model stress and strain tensors. We find that the observed axial and transverse strain-stress curves start to deviate significantly from those predicated by Hookean elasticity when the rate of observed acoustic emission events has a sharp increase. The predications of the elastic damage model of Lyakhovsky et al. [1997] can fit the observations well beyond the range of linear elasticity, but not over the entire deforming range associated with distributed damage. The new model, with the additional effective viscosity, significantly improves the quality of the fitting results for all tests consistently. Both predicated axial and transverse stress-strain relations of the visco-elastic damage model fit the observations very well up to the final brittle failure.

Refraction microtremor and optimization methods for site strength and earthquake hazard assessments

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Evaluation of shallow shear velocity is important to both earthquake-hazard assessment and efficient foundation design. Borehole-based methods (downhole, crosshole) require both drilling and measurement activities. This makes them expensive point measurements, unsuitable for many preliminary investigations. We tested two alternative surface-based methods for estimating shallow shear velocities with seismic refraction equipment. We demonstrate comparisons at the sites of several boreholes in California and Nevada, at sites of precariously balanced rocks near the 1857 rupture of the San Andreas fault, and on weathered rock at the crest of Yucca Mountain, Nevada. The sites ranged from hard to soft (NEHRP hazard classes A to D). The first method, refraction microtremor (ReMi), uses ambient ground noise (recorded as in ASTM D5777) and wavefield analysis to identify Rayleigh-wave phase velocities. It works well in dense urban areas and transportation corridors. At quiet rural sites with hard rock, estimating phase velocities below a few meters depth requires a simple energy source such as a weight drop or a rolling truck. Depth-averaged shear velocities are available in the field within a few minutes of recording. The second method, SeisOpt(R)@2d by Optim LLC, takes standard (ASTM D5777) seismic refraction arrival picks and finds an optimized 2-d P-velocity model. Laterally heterogeneous velocity models are available within an hour of recording. We compare the effects of downhole, refraction-microtremor, and SeisOpt(R) velocity results on surface spectra. For the sites tested, shear velocities estimated from both surface methods are just as effective as borehole velocities for two purposes: estimating 3-meter depth-averaged shear velocity for foundation design; and estimating the spectral seismic site-transfer function for earthquake-hazard evaluations of sites.

Record of Holocene and Latest Pleistocene Activity on the Mesquite Lake Fault Near Twentynine Palms, California

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Paleoseismic results from two excavations across the Mesquite Lake fault, a part of the eastern California shear zone (ECSZ) near Twentynine Palms, California, reveal evidence for a minimum of three prehistoric earthquakes, with two large surface rupturing events in the last 10.2 ka. AMS ^{14}C dates from detrital charcoal collected from playa sediments indicate that the most recent prehistoric event occurred between 2.7 and 7.4 ka, preceded by a penultimate event between 7.7 and 10.2 ka. This suggests that the Mesquite Lake fault experiences long recurrence intervals between several hundred and several thousands of years, similar to other faults of the ECSZ. The vertical separation of playa sediments produced by each event is similar, suggesting that the Mesquite Lake fault experiences characteristic earthquakes. Offset fluvial deposits at the playa site indicate a slip rate of < 1mm yr^{-1} for the Mesquite Lake fault, which is comparable to other faults in the ECSZ.

The surface rupture of the October 1999, M_w 7.1 Hector Mine earthquake terminated near a complex right step between the northern margin of the Mesquite Lake fault 15 km northwest of the trench site and the Bullion fault. The Mesquite Lake fault may have acted as a boundary to the continuation of the Hector Mine rupture. Low pre-stresses on the Mesquite Lake fault, resulting from a release of strain during the most recent event, could have prevented the Bullion fault from transferring slip across a dilational step onto the Mesquite Lake fault.

Paleoseismic results from faults in the western ECSZ, including those that ruptured during the 1992 Landers earthquake, suggest earthquake activity in the region occurs in temporal clusters centered at 0-1 ka, 5-6 ka, and 8-9 ka. New paleoseismic data from faults east of the Landers rupture show activity between 1-5 ka, which is considered a period of quiescence for the western ECSZ. This may indicate that clusters of earthquakes migrate spatially across the ECSZ.

Relative Contributions of Crustal Temperature and Composition to Controlling the Depth of Earthquakes in Southern California

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The maximum depths of earthquakes in southern California vary over a ~13 km range. Previous work has attributed the depth range variations as primarily due to either crustal temperature or crustal rock composition variations. Here I compare heat flow (a proxy for crustal temperature) to local maximum depths of earthquakes ($\delta 95$), defined as the depth above which 95 percent of the earthquakes occur, interpreted to mark the onset of plastic behavior. Each heat flow- δ 95 pair is assigned to a best-guess rock composition category (granite, schist, or mafic). A plot of heat flow versus δ 95 produces distinct trends for the different rock types; each trend represents an isotherm of the temperature at which each rock type becomes plastic. Offsets between the trends measure the differences in the plastic behavior temperatures of each rock composition; these offsets are comparable to the $\delta 95$ variations with heat flow. Thus, temperature and composition contribute about equally to the control of the maximum depths of earthquakes.

Upper Mantle Heterogeneities Incorporated into the SCEC Southern California Reference Three-Dimensional Seismic Velocity Model Version 3

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We extend the SCEC southern California reference model to the upper mantle by incorporating seismic velocity heterogeneities obtained by teleseismic travel-time inversion. Teleseismic P-wave travel times are obtained from three LARSE passive experiments and SCSN stations; raypath coverage is good over the study area. The inversion is performed using a damped least squares LSQR conjugate gradient method. The inversion model element spacing is 20 km. Prior to the inversion, the effects of crustal velocity heterogeneities (as represented by the SCEC version 2 model) are removed from the teleseismic travel times. This demonstrates the utility of the top-down method of the SCEC model development. The inversion produces a variance reduction of 36 per cent. S-wave velocities are determined from laboratory Vp/Vs relations.

The most prominent features imaged in the results are high P-wave velocities (+3 per cent) in the uppermost mantle beneath the northern Los Angeles basin, and the previously reported high velocity anomaly (+3 per cent) to depths of 200 km beneath the San Gabriel Mountains and the San Andreas fault.

PML absorbing boundary method: an application to 3D 4th-order velocity-stress finite-difference schemes

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Robust absorbing boundary conditions are central to the utility and advancement of 3D numerical wave propagation methods. In general, it is preferred that an absorbing boundary method be capable of broadband absorption, is easily tuned and is efficient in terms of memory and computational time. Here, we present results on the application of such a method, PML (perfectly matched layers; Collino and Tsogka, 2001), to a 3D velocity-stress finite-difference scheme. Our elastic scheme incorporates a free surface (Gottschammer and Olsen, 2000) in the internal propagation space as well as in the PML regions. The internal propagation space, which utilizes 4th-order difference operators, is combined with 2nd-order operators in the PML regions. The PML model is formed, for a particular plane region, by partitioning the velocity-stress system based on perpendicular and parallel spatial derivative separation, with a damping term being added to the perpendicular component. For the edges and corners, damping terms are added in all directions for which there are bounding planes. This particular construction theoretically results in a reflection-free interface between the internal propagation space and the PML absorbing regions.

Numerical results for a homogeneous structure, realistic source mechanisms and different thickness PML zones are excellent. In general, seismograms produced in conjunction with PML absorbing regions result in no observable reflections compared to the amplitude of the primary phases. Typical amplitude reduction factors (with respect to the maximum trace amplitude) in the presence of Rayleigh waves, are 1/100, 1/250 and 1/500 for PML thicknesses of 5, 10 and 20, respectively. Reduction factors are even greater for body waves only. The PML results are also compared with those of a basic Cerjan et al. (1985) absorbing boundary region of thickness 20, with the PML region of thickness 5 still outperforming the Cerjan et al. method by a factor of 2. Although, the PML method requires additional memory for storage of the perpendicular and parallel wavefield variables in the absorbing regions, its computing efficiency and storage requirements, compared to Cerjan et al., are actually reduced due to the need for only narrow absorbing regions. For example, for our particular model space, a thickness 5 PML scheme required about 80% the memory and 40% the computation time as compared to a thickness 20 Cerjan et al. scheme.

PBIC 2001: Highlights of the Last Ten Years

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For the past decade the SCEC has supported the Portable Broadband Instrument Center that has provided SCEC researchers with a valuable, albeit small number, of portable recorders/sensors to support their field experiments. While the PBIC has been fully supportive of SCEC researchers in their individual projects, the PBIC's response to four significant earthquakes in Southern California in the last decade has highlighted and emphasized the utility of the PBIC. In each of the earthquakes—Joshua Tree, Landers, Northridge and Hector Mine—the PBIC played a critical role while learning from the different challenges and logistical problems presented by the earthquakes. From the remote, high-desert sites of Joshua Tree and Landers to the urban sprawl of the San Fernando Valley to the highly restricted access at the 29

Palms Marine Base, the PBIC has played a supporting and sometimes even leading role in these SCEC aftershock deployments.

In addition to the SCEC earthquakes, the PBIC has provided equipment and assistance to more than 30 SCEC related research projects. Experiments range from large active source experiments such as LARSE with several hundred instruments, moderate sized experiments like the trapped wave studies requiring 10-20 instruments, to the small, short-term passive monitoring requiring only one or two instruments. Early PBIC efforts included the development of software to help acquire and visualize the data collected by the portable recorders. This software improved the quality control and facilitated preliminary analysis. In a later development the PBIC developed an efficient and accurate calibration method for passive sensors. Recent software developments have been focused on information sharing using the internet. These efforts include web access to the Hector Mine portable data, the equipment database with it's web interface, and improved online documentation.

The PBIC has been a great success over the last decade with over two dozen journal publications using data collected with PBIC equipment. The responsiveness and effectiveness of the PBIC to the needs and demands of the SCEC scientific community have demonstrated the importance of this facility for reaching the SCEC objectives.

Present Day Kinematics of the Eastern California Shear Zone from a Geodetically Constrained Block Model

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We use Global Positioning System (GPS) data from 1993–2000 to determine horizontal velocities of 65 stations in eastern California and western Nevada between 35_ and 37_ N. We relate the geodetic velocities to fault slip rates using a block model that enforces path integral constraints over geologic and geodetic time scales and that includes the effects of elastic strain accumulation on faults locked to a depth of 15 km. The velocity of the Sierra Nevada block with respect to Nevada is 11.1 ± 0.3 mm/yr, with slip partitioned across the Death Valley, (2.8 ± 0.5 mm/yr), Panamint Valley (2.5 ± 0.8 mm/yr), and Airport Lake/Owens Valley (5.3 ± 0.7/4.6 ± 0.5 mm/yr) faults. The western Mojave block rotates at 2.1 ± 0.8°/My clockwise, with 3.7 ± 0.7 mm/yr of left lateral motion across the western Garlock Fault. We infer 11 ± 2 mm/yr of right lateral motion across the Mojave region of the Eastern California Shear Zone.

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Paleoseismology of the San Andreas fault at Plunge Creek, near San Bernardino, southern California

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We have examined and documented several trenches across the south branch of the San Andreas fault at the Plunge Creek site, near San Bernardino, southern California. In all of the trenches, no faulted sediments that are clearly younger than AD 1440-1640 have been identified. In the five trenches we have studied in the most detail, the most recent faulting event (event W) is overlain by unfaulted strata from which 19 of the 20 dated charcoal samples have ages ranging from AD 1440 to 1640 (or older), and the 20th sample is most likely older than AD 1680. No evidence for earthquakes younger than this has been found at the Plunge Creek site, despite a thorough search. The most recent excavation, trench 10, has decent stratigraphy throughout its 60-m-length and eliminates the possibility of additional, significant, recently active fault strands that could have been present but not visible within a few localized massive areas in the previous trenches. Two of the trenches reveal suggestive evidence for an older faulting event (event R), which post-dates AD ~1200.

Given that the ages of the detrital charcoal samples may overestimate the depositional ages of the layers, the dates mentioned above do not provide a firm younger bound on the date of the youngest faulting event. However, even after we apply an estimate of the inherited age of the samples at the time of deposition, the most likely date for this event is around AD ~1600. If this faulting event correlates with one of the events documented at other paleoseismic sites to the northwest, then both the AD ~1600 and AD ~1700 earthquakes are likely candidates. It seems quite unlikely (we are in the process of estimating the probability) that the youngest faulting event at the Plunge Creek site represents the AD 1812 earthquake, which has been documented farther northwest. We suggest that the most reasonable interpretation is that the southeastern terminus of the AD 1812 earthquake rupture was somewhere between Pitman Canyon and Plunge Creek, within the northwestern half of the San Bernardino mountains segment of the San Andreas fault. If the AD 1812 earthquake did not rupture the entire length of the San Bernardino Mountains segment of the fault, as we suggest, then the amount of strain accumulated on the southeastern half of the San Bernardino Mountains segment may be substantially greater than previously assumed.

Space-Time Imaging of Aseismic Slip Transients on Subduction Zone Thrust Interfaces

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Dense arrays of GPS receivers have recently recorded aseismic slip events with durations ranging from days to months. We describe a time dependent inversion method for estimating the temporal and spatial distribution of fault slip, building on the concept of a Network Inversion Filter [Segall and Matthews., 1997, J.G.R.]. The NIF employs time-domain Kalman filtering, and allows for non-parametric descriptions of slip velocity, local benchmark motion, and measurement error. Recent advances include, explicit consideration of rotations and translations

of the GPS reference frame, non-negativity constraints, and direct estimation of the spatial and temporal smoothing hyper-parameters.

From late 1996 to late 1997 aseismic slip on the Philippine Sea plate subduction interface beneath Kyushu and Shikoku islands produced large transient deformation signals which began as afterslip subsequent to two Mw 6.7 Hyuga-nada earthquakes. The afterslip was then followed by the Bungo Channel slow earthquake centered about 100 km further north [Hirose et al, 1999]. While these two events overlap in time, our inversion demonstrates that the afterslip and the Bungo Channel slow earthquake were separated by a 50 km long region of little to no slip. The peak slip in both events occurred between depths of 35 and 50 km. Peak slip rates were ~.4 m/yr in the afterslip event and ~1.2 m/yr in the Bungo channel event. The Bungo Channel slow earthquake nucleated on the shallow portion of the thrust interface and propagated deeper.

In 1997 the Cascadia subduction interface beneath Seattle and Vancouver Island ruptured in an aseismic slip transient that lasted about 6 weeks [Dragert et al. 2001]. Inversion of the available GPS data demonstrates that the event nucleated at a depth of around 30 km and propagated initially to the south and then dominantly along-strike to the north as well as updip. The duration of slip at any point on the fault is much shorter than the Bungo Channel event, and peak slip-rates were ~ 0.5 m/yr. The rupture velocity may have been spatially variable.

The differences between the Cascadia and Bungo Channel slow earthquakes in rise-time and rupture propagation, suggest that a rich variety of aseismic-slip transients can occur on subduction zone thrust interfaces. The failure mechanism allows instabilities that accelerate to maximum slip-rates on the order of 1 m/yr.

Seismic Profile in Southern California

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During Phase II of the Los Angeles Region Seismic Experiment (LARSE), data were collected along a 150-km-long profile trending NNE from Santa Monica Bay to the southern Sierra Nevada. The profile was designed to image sedimentary basins and faults. It extended northward from Santa Monica Bay to the southern Sierra Nevada. Seismographs were spaced at 100-m intervals from Santa Monica Bay well into the western Mojave Desert and shots were spaced at approximately 1 km intervals. Of the 1000 instruments deployed, most were single component with vertical geophones. However, 3-component instruments were interspersed roughly every 500 meters along the southern 100 km.

High-quality S-waves were generated by shots in the north-central Transverse Ranges north of the San Francisquito fault (SFF), and in the southernmost part of the western Mojave Desert. Along the LARSE II transect, this part of the Transverse Ranges is composed of Precambrian igneous and metamorphic rocks and Mesozoic plutons. North of the San Andreas fault (SAF) in the southernmost part of the Mojave desert, the rocks/sediments are underlain chiefly by Mesozoic plutonic rocks. Lower-quality S-waves were generated in the Santa Monica mountains, north of Santa Monica Bay, and in the Sierra Pelona, in the north-central Transverse Ranges south of the SSF. Along the LARSE II transect, the Santa Monica mountains are underlain by early Cenozoic sedimentary and volcanic rocks that form a thin veneer over Jurassic slate, and the Sierra Pelona is underlain by the Mesozoic Pelona schist.

We pick P and S wave arrival times chiefly on vertical-component seismograms, and we use horizontal component seismograms to check them. Here, we show record sections with high-quality S-waves from the Transverse Ranges north of the SFF and from the Mojave Desert.

Subsidence, Compaction and Gravity-Sliding: Implications for Active 3D Fault Geometry, Dynamic Rupture and Seismic Hazard in Southern California

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The highest rates of measured geodetic shortening in southern California occur across the Los Angeles and Ventura basins. This surface deformation is inferred to represent a significant seismic hazard, and is presumed to be largely accommodated by active hanging-wall faulting, folding, and tectonic uplift. In southern California, however, these deep, subsiding basins are often bounded by oblique reverse faults that thrust early-Cenozoic and older rocks over young unconsolidated sediments. This suggests that footwall deformation, subsidence, and compaction may play an important role in contributing to the apparent high rates of crustal strain. Although often neglected, effects like compaction can be significant. Even in the absence of active crustal shortening, sediment compaction alone can produce surficial motions that mimic deep fault slip or elastic strain accumulation. Differential subsidence, pressure solution, and 3D compaction of footwall sediments relative to hanging-wall basement rocks can lead to increased vertical separation and fault rotation about horizontal axes. Such effects would contribute to net horizontal and vertical motions in both geologic and geodetic data, and—if not properly accounted for—would result in incorrect estimates of the inferred seismic hazard.

More importantly, subsidence and compaction can increase the potential for gravity-sliding towards the basin and the development of significant non-planar 3D fault geometry. A prime example occurs along the San Cayetano fault that bounds the eastern Ventura basin. Detailed structure contour maps and cross sections of the fault surface derived from industry subsurface well data reveal a fault geometry reminiscent of thrust nappes in the western Alps. At shallow levels, a thin-skinned thrust sheet (the Modelo Lobe) with low dip extends out in front of the deep, steeply-dipping fault segment by over 4 km, is nearly 2 km thick, and occupies over 60 cubic km. This geometry is strongly indicative of gravity-driven (sackungen-type) failure resulting from hanging-wall uplift and basinward tilt enhanced by footwall subsidence and compaction. Failure of this mega-slide off the hanging-wall block most likely occurred within the Rincon Formation, a ~400-m thick ductile shale sequence that often accommodates bedding-plane or detachment slip. Further reactivation of the slide may have been accommodated by additional shale layers within the Modelo Formation, and augmented by the presence of overpressured fluids trapped below the base of the slide as a result of continued sediment compaction and overburden loading.

The thrust-nappe geometry of the San Cayetano fault has significant implications for how the fault might behave during dynamic rupture. Dynamic slip may be inhibited at shallow levels by the presence of the slide and the change in fault dip with depth; however, if the shallow thrust sheet does fail, the shallow slip may or may not be related to tectonic slip on the deep fault segment. If the thrust-nappe geometry is the result of an ancient gravity slide, the slide can be reactivated independent of slip at depth and/or aseismically. Large ruptures may reactivate the slide, either by dynamic triggering of the weak slide surface or by statically pushing the thrust wedge from behind. In either case, observations of near-surface slip or large slip events at the toe of the slide may not be indicative of tectonic slip or large earthquakes at depth on the fault. The hazard associated with such deep-seated slides is increased by their possible occurrence in oversteepened terrain, their large potential slip (unrelated to accumulated elastic strain), and by the high accelerations that may be produced if dynamic rupture is abruptly terminated at shallow depth when it encounters the slide.

ROSRINE: Continuing Field and Data Dissemination Activities

Robert Nigbor and Jennifer Swift, University of Southern California
John Diehl, GeoVision Geophysical Services

ROSRINE (*Resolution of Site Response Issues in the Northridge Earthquake*) is an on-going government-academia-industry research collaboration focused on improving engineering models of earthquake ground motion through collection, synthesis, and dissemination of data on subsurface conditions at key Strong Ground Motion (SM) station sites in California. Since 1996 a total of more than 50 SM sites have been characterized using drilling, borehole logging, surface geophysics, and laboratory testing. Results show that many sites previously have been misclassified and that detailed site characterization of important seismic stations is important to the understanding of recorded ground motions. Finishing up in October 2001, the current PEER-funded ROSRINE Phase 5b includes further investigations of SM sites in California and enhanced data dissemination. Data are publicly disseminated through the project's web site http://geoinfo.usc.edu/rosrine. Future phases are being planned.

Estimation of Q and Near-surface Soil Amplification for the LA basin

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Chris Bradley, Los Alamos National Laboratories
Steven Day, San Diego State University

We have simulated 0-0.5 Hz 3D wave propagation through the Southern California Earthquake Center (SCEC) velocity model 2 of the Los Angeles (LA) basin for the 1994 Northridge earthquake in order to examine the effects of anelastic attenuation and amplification of the near-surface sediments. We use a fourth-order finite-difference (FD) staggered-grid method with the coarse-grained viscoelastic scheme by Day and Bradley (2001) and the combined slip inversion results for Northridge by Wald et al. (1996). Previous FD simulations for the LA basin, with the lowest S-wave velocity artificially constrained to values near 1 km/s due to computational limitations, have found that the use of the relations Q_s 0.1 Vs (m/s) and Q_p 1.5 Qs provided a satisfactory fit to data (e.g., Olsen, 2000). However, we find that lowering the minimum velocity from 1 km/s to 0.5 km/s increases the amplification to an extent where the above relation generates significant overprediction of the basin motions if this relation for Q is used. Instead, our preliminary FD simulations suggest that the relations Q_s 0.02 V_s (m/s) or Q_s of a constant value of about 30 provide a much improved fit of synthetic and observed peak velocities above the deepest part of the basin.

Ground Motion Synthetics for Spontaneous Versus Prescribed Rupture on a 45° Thrust Fault

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We have compared prescribed (kinematic) and spontaneous dynamic rupture propagation on a 45° dipping thrust fault buried between 0 and 5 km in a half-space model, as well as ground motions on the free surface for frequencies less than 1 Hz. The computations are carried out using a 3D finite-difference method with rate-and-state friction on a planar, 20 km by 20 km fault. We use a slip-weakening distance of 15 cm and a slip-velocity weakening distance of 9.2 cm/s, similar to those for the dynamic study for the 1994 M6.7 Northridge earthquake by Nielsen and Olsen (2000) which generated satisfactory fits to selected strong motion data in the San Fernando Valley. The prescribed rupture propagation was designed to mimic that of the dynamic simulation at depth in order to isolate the dynamic free-surface effects. In this way, the results reflect the dynamic (normal-stress) interaction with the free surface for various depths of burial of the fault. We find that the moment, peak slip and peak sliprate for the rupture breaking the surface are increased by up to 60%, 80%, and 10%, respectively, compared to the values for the scenario buried 5 km. The inclusion of these effects increases the peak displacements and velocities above the fault by factors up 3.4 and 2.9 including the increase in moment due to normal-stress effects at the free surface, and up to 2.1 and 2.0 when scaled to a Northridge-size event with surface rupture. Similar differences were found by Aagaard et al. (2001). Significant dynamic effects on the ground motions include earlier arrival times caused by super-shear rupture velocities (break-out phases), in agreement with the dynamic finite-element simulations by Oglesby et al. (1998, 2000). The presence of shallow low-velocity layers tend to increase the rupture time and the sliprate. In particular, they promote earlier transitions to super-shear velocities and decrease the rupture velocity within the layers. Our results suggest that dynamic interaction with the free surface can significantly affect the ground motion for faults buried less than 1-3 km. We therefore recommend that strong ground motion for these scenarios be computed including such dynamic rupture effects.

Quantitative Inversion of Seismic Fault Zone Waveforms in the Rupture Zone of the 1992 Landers Earthquake for Structural Properties at Depth

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Waveform modeling of seismic fault zone (FZ) trapped waves has the potential for providing a high-resolution imaging of seismic velocities, seismic attenuation, FZ width, and structural continuity at depth. From a digital waveform data set generated by 238 aftershocks of the 1992 Landers earthquake [William Lee, per. comm., '99], we identified 60 events with good candidate trapped waves. Each event was recorded by 33 three-component, short-period (2 Hz), L-22 seismometers, 22 of which on a line crossing the surface rupture zone of the mainshock. Locations of 102 events out of the 238 aftershocks are given in the catalog of Richards-Dinger and Shearer [JGR, '00]. These include 16 events generating candidate trapped waves. A plane-wave fitting technique is applied to estimate the back-azimuth angle of the unlocated events that produce candidate trapped waves. The source-receiver distance for these events is estimated from the S - P travel time. Of the 60 candidate trapped waves, about 75% are generated by events with locations close to the FZ, while the reminder are likely produced by events at considerable distance from the fault. The latter observation is compatible with 3D numerical calculations of Igel et al. [Pageoph, '01].

The FZ waveforms with candidate trapped waves are modeled with a genetic inversion algorithm (GIA) that maximizes the correlation between observed and synthetic waveforms [Michael and Ben-Zion, ms. in preparation, '01]. The synthetic seismograms are generated with a two-dimensional analytical solution for a scalar wavefield in a layered vertical FZ between two quarter-spaces [Ben-Zion and Aki, BSSA,'90; Ben-Zion, JGR, '98]. Our previous results showed that the GIA is able to provide very good fits for Landers FZ waveforms with a model consisting of a single uniform FZ layer in a half space. However, it is possible to get equally good fits for a wide range of parameters. This is due to significant trade-offs among FZ width, propagation distance along the fault, source offset from the fault, velocity contrast, and attenuation. To overcome these difficulties, we developed an analysis procedure consisting of the following steps: (1) Improved initial identification of candidate trapped waves using the distribution of waveform amplitude spectra recorded by the linear seismic array across the fault. (2) Travel time tomography for obtaining constraints on the seismic properties of the surrounding region (for the Landers area, this has already been done by Hauksson [JGR, '93]). (3) Dispersion analysis of candidate trapped waves. The group velocities of the waves are measured from multiple band-pass-filtered seismograms using zero-phase Gaussian filter. The dispersion of trapped waves is shown more clearly as the source-receiver distance increases. Results from the dispersion measurements, combined with estimates of uncertainties associated with location and the travel time errors, and the trade-offs between FZ width, velocity contrast, and attenuation, provide additional constraints on the ranges of allowable parameters. (4) Simultaneous GIA modeling of multiple FZ waveforms. (5) Determination of best-fitting parameters, their spreads, and associated confidence limits.

We obtain excellent fit between synthetic waveforms and seismograms recorded by the 22 stations across the Landers FZ for the following ranges of FZ parameters: width 150-350 m, shear velocity reduction relative to the host rock 20-40%, and shear wave attenuation coefficient 20-60. Detailed results will be presented in the meeting.

Protoype 3-D Fault Model for the Los Angeles Basin, CA

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We present a digital 3d model of the major, seismogenic fault system in the Los Angeles basin. Faults included in the model were selected by consensus within the SCEC2 community based on geologic relevance, perceived hazard, and quality of descriptive data. Constraints on fault geometries and positions include surface traces, surficial neotectonic data, seismic reflection profiles, wells, cross-sections, hypocentral locations, and focal mechanisms. We use advanced geometric modeling software to integrate these various geophysical and geologic data in a 3d space, and to interpolate and extrapolate the fault surfaces.

Our first iteration model was populated with most of the important faults and with the deformed basement surface, which represents the main seismic velocity interface in the basin. The process of integrating the data and generating this model, which required precise geospatial registration and digitalization, defined a number of minimal data requirements for inclusion of faults. Contributions to the SCEC2 community fault model should meet these basic requirements.

The current model describes the geometry of imbricated blind-thrust faults that underlie the northern Los Angeles basin (Puente Hills, Las Cienegas, San Vicente, Elysian Park), as well as the basin bounding structures including the Santa Monica, Sierra Madre, and Cucamonga systems. In the case of the Santa Monica thrust, the 3d construction suggests the presence of a previously undocumented blind extension of this system to the northeast, below the Hollywood fault, and perhaps coinciding in parts with the North Salt Lake fault. The model also describes the 3D geometry of the major strike-slip systems in the basin, including the Newport-Inglewood and Whittier faults. The model is a prototype for a community-based fault characterization effort within SCEC2 and provides a medium to investigate the spatial and temporal interactions of these fault systems based on their precise 3D geometries.

The Southern California Fault Activity Database

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Matias P. Silva, United States Geological Survey

Funded by SCEC, the Southern California Fault Activity Database (SCFAD) will supply WEB-accessible data about active faults throughout southern California, an essential resource for basic research and earthquake hazard mitigation. The SCFAD compiles and summarizes published data pertaining to each fault's slip rate, recurrence interval, slip per event, and known damaging earthquakes, as well as fault location, orientation, and sense of movement. It is based predominantly, but not exclusively, on paleoseismic studies. In addition, the SCFAD archives publications and unpublished data, provides a forum for continuing discussion about fault activity, and highlights needed future research directions. A key goal is to develop a single, consistent representation of the region's faults. Thus, the SCFAD has contributed to, and is designed to coordinate with, databases of the California Division of Mines and Geology, the National Hazard Mapping Program, and 3-D fault geometry models of SCEC's Regional Earthquake Likelihood Models (RELM) project. The SCFAD builds on several existing databases, particularly a Web-based database of Los Angeles basin faults constructed by Ponti, Hecker, Kendrick, and Hamilton at the U. S. Geological Survey. The SCFAD is implemented using FileMaker Pro (v. 5) as a database management system (DBMS) which resides on a Windows 2000 server. The SCFAD will soon be available on-line, viewable through any W3C-compliant Internet browser. Please keep apprised of SCFAD progress at www.relm.org. Collaborations are fundamental to the SCFAD's mission, and we encourage you to participate in the SCFAD's continued growth through use, contributions, and comments.

An Empirical Model for Earthquake Probabilities in the San Francisco Bay Region, California, 2002-2031

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The moment magnitude M7.8 earthquake in 1906 profoundly changed the rate of seismic activity over much of northern California. The low rate of seismic activity in the San Francisco Bay region (SFBR) since 1906, relative to that of the preceding 55 years, is often explained as a "stress shadow" effect of the 1906 earthquake. However, existing theoretical models of stress change and its effect on the rate of earthquake activity fail to predict the strength, duration, or regional extent of the lower rate of activity. We use observed variations in the rate of $M \geq 5.5$ events before and after 1906 and in the rate of $3.0 \leq M \leq 5.0$ earthquakes since 1942 as a basis for a simple, empirical model for the occurrence of $M \geq 6.7$ earthquakes in the SFBR since 1906. This model is consistent with the occurrence of the four $M \geq 6.7$ earthquakes in this region since 1838. In addition, it preserves the magnitude distribution of sources predicted by the WGCEP (1999) model of characteristic ruptures on SFBR faults. When the model is extrapolated 30 years forward from 2002, it gives a probability P of 0.4 for one or more $M \geq 6.7$ in the SFBR. This result is less than the regional probability of 0.5 estimated by WGCEP (1988), less than the Poisson probability of 0.6 obtained by WGCEP (1999), and stands starkly in contrast to P=0.67 and P=0.70, estimated by WGCEP (1990) and WGCEP (1999), respectively, for the occurrence of one or more $M \geq 6.7$ earthquakes in the coming 30 years.

3D Geometry and Seismogenic Potential of the Inner California Borderland Blind Thrusts System

Carlos Rivero and John H. Shaw
Harvard University

We describe the complex geometry and tectonic activity of the Inner California Borderland blind-thrust system, located offshore southern California. These faults are defined using three-dimensional structural and velocity modeling that incorporate seismic reflection profiles, well control, surface and seafloor geology, and precisely re-located earthquakes.

The Inner California Borderland blind-thrust system includes a pair of inverted Miocene extensional detachments that originated during Neogene rifting. These detachments were

reactivated as low-angle thrust faults during the Pliocene, when a change to regional transpression inverted the Miocene extensional depocenters, uplifting previously depressed hanging walls. Thrust motions on these detachments produced several trends of contractional fault-related folds (e.g., San Mateo and Carlsbad structures) that partition oblique convergence with regional strike-slip systems.

Earthquake hypocenters and growth structures record the style of this complex structural inversion, and suggest that the Inner California blind thrust system is active and seismogenic. Moreover, our results suggest a genetic correlation between this offshore blind-thrust system and several coastal and onshore faults located in the Los Angeles Metropolitan region.

Completion and Publication of SCEC-Funded Projects

Tom Rockwell, San Diego State University
Scott Lindvall, William Lettis & Associates

During this final year of SCEC 1, we focused on completing and submitting for publication several projects that have been wholly or partially supported by SCEC. Specifically, work has been completed on the Hollywood, San Andreas, Lavic Lake, Elsinore/Whittier, and North Anatolian faults. Each is discussed briefly below.

Hollywood Fault - We completed a series of hollow-stem and bucket augers (privately funded) to further our understanding of the Hollywood fault in West Hollywood. Cross-sections have been completed and a draft version of a paper completed. The draft is in review by the co-authors and is expected to be submitted within the next few weeks. The core aspects of our work are: 1) the pronounced mountain front along Sunset Blvd. is the back-edge of a marine terrace in West Hollywood, although to the east, it is coincident with the Hollywood fault. The marine terrace is 400-900 ka in age based on the chronology of a sequence of overlying paleosols (probably oxygen isotope stage 15 at 600 ka), with a paleo-shoreline at about 100 m elevation (hanging wall). This age compares favorably with the age of the marine sediments identified in the La Brea Plain at about 57 m elevation, south of our study area. These observations indicate that the late Quaternary rate of uplift of the Hollywood Hills is about 0.12-0.28 mm/yr. Comparing the elevations of the hanging wall terrace to that south of the fault in La Brea Plain, the differential uplift rate across the Hollywood fault is lower, on the order of 0.06-0.14 mm/yr.

San Andreas fault at Frazier Mountain – We completed and submitted for review our SCEC-funded research on the San Andreas fault at Frazier Mountain. The paper is in review at BSSA for the special volume on the San Andreas fault. The final conclusions of our work are that only the ca 1500 and 1857 earthquakes have ruptured the San Andreas fault during the past 600 years at Frazier Mountain. No evidence was found for the 1812 earthquake.

Hector Mine Paleoseismic Studies – After the Hector Mine earthquake, we organized and orchestrated a major collaborative paleoseismic campaign with the USGS. Three sites were developed and studied, with experiments including trenching, surface exposure dating, and geomorphic mapping. The Lavic Lake site, led by Mike Rymer (USGS) and including several SCEC researchers has been completed and a paper submitted for the special volume on the earthquake. The two other sites (drainage divide and Bullion fan) are awaiting completion of the surface exposure dating program. All logs are drafted and portions of a draft paper, dealing specifically with the interpretation of past events, is already completed. Our observations indicate that: 1) the Bullion fault has ruptured only once during the past 7000 years, probably indicating a low slip rate. The current precision of the dates does not allow for comparison to other Mojave events, but this will improve with additional dating; 2) the Lavic Lake fault at the drainage divide has a very long return period. The penultimate event appears to have occurred several tens of thousands of years ago, and the fault would have been considered inactive (pre-

Holocene) if it had been studied prior to the 1999 earthquake. In contrast, the Lavic Lake fault in Lavic Lake shows evidence for a prior Holocene event, although it is on a nearby parallel strand. That is, the 1999 earthquake did not exactly follow the previous rupture. This may reflect that the Lavic Lake portion of the 1999 rupture also breaks with other faults, such as the Pisgah fault.

Elsinore/Whittier Fault – SCEC supplied funding for two studies along the northern Elsinore and Whittier faults, with the balance of funds being supplied by the USGS NEHRP program. The Elsinore 3-D trenching results are now finalized and being submitted to BSSA. The final rate is 4.9 +0.9/-0.5 mm/yr for the past 2 ka, based on 3D trenching of a subsurface offset channel. The Whittier studies include trenching, geomorphic mapping and age dating at four principal sites along the Whittier fault from Horseshoe bend in Yorba Linda to the Olinda oil field at the Orange/LA County line. The slip rate decreases from about 2.5 mm/yr at Yorba Linda to 2 mm/yr or less at Olinda. To the northwest of Olinda, the geomorphic expression of the fault degrades, probably indicating a consequent decrease in rate. We interpret this to reflect an increase in folding and blind thrusting, and a decrease in strike-slip to the northwest.

Survey Measurements of Slip in Turkey earthquakes – After the Izmit earthquake, PG&E commissioned a study to survey offset features along the 1999 rupture. SCEC supported the travel of Rob Langridge to join us in that endeavor, so we include this as a partially SCEC-supported project. Our results from that study, which are in final review for the BSSA special volume on the Izmit earthquake, show that there are surprisingly large lateral variations of slip magnitude along fault strike. We surveyed long tree lines and other features to capture both brittle and off-fault warping deformation. We note variations in lateral slip of up to a meter over distances of less than 50 m.

Evaluation of Earthquake Potential in China

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We present an earthquake potential estimation for magnitude 5.4 and larger earthquakes for China. The potential is expressed as the rate density (that is, the probability per unit area, magnitude, and time).

We constructed a special earthquake catalog which combines previous catalogs covering different times. We estimated moment magnitudes for some events using regression relationships that we derived. We used the special catalog for constructing our smoothed seismicity model and testing it retrospectively. We estimated the completeness threshold, the b-value, and the upper magnitude limit using maximum likelihood.

The smoothed seismicity method assumes that the rate density is proportional to the magnitude of past earthquakes and approximately on a negative power of the epicentral distance out to a few hundred kilometers. We adopted a kind of Gutenberg-Richter distribution with modifications at higher magnitude. We assumed a uniform b-value and upper magnitude limit derived from the special catalog. We estimated local "a-values" from smoothed seismicity. We have begun a "prospective" test, and earthquakes since the beginning of 2000 are quite compatible with the model.

A Simple Analytic Model for the Formation and Dissolution of Stress Shadows from Large Earthquakes

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Accelerating seismic moment release has been observed to precede many large earthquakes. This acceleration is usually quantified in terms of the cumulative Benioff strain $s(t) = \sum_{i=1}^{N(t)} E_i^{1/2}$, which is fit to a time-to-failure equation of the form $s(t) = A - B(t_c - t)^m$ where m=0.3. Because this equation also describes the behavior of thermodynamic systems near a critical point, the mathematical framework developed by statistical physicists to describe critical systems has been used to characterize regional seismicity. In this view, a large earthquake is only possible when a region is in a critical state characterized by long-range spatial correlations of highly stressed patches that allow the propagation of a large rupture. The large earthquake then lowers the stress field on its fault network destroying long-range correlations and moving the region away from the critical state. Subsequent tectonic loading and small events move the region back toward the critical state and the next large event. In this study, we use a simple analytical dislocation model to study the dissolution of the stress shadow from a large event. We assume a Gutenberg-Richter distribution of seismicity in which the b-value remains constant while the a-value is a function of the depth of the stress shadow at every point. This simple model reproduces many observed characteristics of seismicity in the precursory region including: 1) the linear scaling of optimal region size with fault length, 2) the occurrence of intermediate events near the periphery of the precursory region, and 3) relative quiescence near the epicenter of the large event. The simplest version of the model that accounts only for tectonic loading and the geometry of the shrinking stress shadow does not produce a singularity in the rate of seismicity implicit in the above equation. However, we find that stress transfer and/or percolation at the shrinking boundary of the shadow can produce singular behavior.

SMALL EARTHQUAKES IN THE CENTRAL TRANSVERSE RANGES: BECONS OF INELASTIC STRAIN ABOVE AND BELOW LARGE RUPTURES

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Earthquakes can be used to characterize geometry and kinematics of seismogenic faults. Seismogenesis may also suggest specific tectonic roles for the faults by the way it responds to stress changes. Seismogenically insignificant faults may be important structurally and for strain accumulation. We produced a set of accurate locations and quality-selected focal mechanisms for southern California from phase data of the Caltech-USGS network in the last three decades. We interpreted these abundant data for seismogenic faults. Much of the data in the central Transverse Ranges is associated with the 1994 Northridge sequence but include also the 1971 San Fernando

aftershocks. Aftershocks provide information on the geometries of mainshock ruptures, but also on many other faults that interact with these ruptures, both structurally and dynamically.

An example is the seismicity triggered by the Northridge mainshock in the hangingwall block of the Santa Susana thrust fault. This seismicity is diffuse and thus involves many faults, yet shows uniform fault kinematics. Abundant and quality-controlled hypocenters and focal mechanisms show slip planes parallel to and kinematically consistent with a major ramp on the Santa Susana thrust fault. We interpret this seismicity to stem from flexural folding of the Santa Susana thrust and its hangingwall block in response to the antithetic reverse 1994 faulting event in the footwall block. Bedding-plane faults associated with flexural folding can be small and characterized by mineral fiber growth. Thus the seismogenic moment released by flexural-slip in the Northridge aftershocks may represent a small portion of the total strain accounted by this folding. Furthermore, folding structurally coupled with a fault appears to take place in tandem with major ruptures on the fault. Thus, part of the elastic strain may be released by folding.

The 1994 rupture as imaged by aftershocks matches well the position, shape, and slip-geometry of the rupture modeled from the mainshock. In addition, seismicity suggests that the rupture is twisted, increasing in dip and in strike (clockwise) with depth. Generally, aftershocks that can be directly associated with the rupture are concentrated at its outer limits, but the densest concentration is at the base of the seismogenic zone. This deep cluster is also unusually stable in rate and slip kinematics. Similar characteristics are noted for deep aftershocks of other large ruptures in California and elsewhere. These aftershocks suggest creep near the brittle-ductile transition and may mark a buffer zone of mixed behavior. They may also therefore account for much more deformation than represented by the seismogenic moment.

Improving Southern California Paleoseismic Chronologies by Integrating Field and Laboratory Research

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Paleoseismology provides a unique long-term perspective, which bears directly on the validity of earthquake models. However, without the addition of accurate paleoseismic records, there appears to be little hope of confidently distinguishing between competing models of fault behavior. The need for improved paleoseismic records has resulted in a corresponding increase in chronological effort, and associated costs. The integration of field and laboratory chronology research combined with multiple-project funding promises chronological improvements and cost savings.

Sedimentary sections are the principle recorders of prehistoric earthquakes. By far, the most common age control of late Holocene sedimentary sections is provided by AMS C-14 determinations. Our experience has clearly shown that improvements in paleoseismic chronologies are limited by a lack of field geologist and laboratory worker communication and understanding, and single-site funding arrangements.

A new approach to achieving better paleoseismic chronologies consists of seamlessly integrating the field and laboratory research tasks by organizing a focused research collaboration between individual field geologists and a chronology research laboratory. As opposed to single-site funding arrangements, in which often the most promising projects are essentially penalized for encountering favorable field conditions that require more extensive C-14 dating than anticipated; the main advantage of the multiple-project approach is the consolidation of the C-14 chronology effort, and the flexibility to apply this effort and the associated funding at the sites where it is warranted. As SCEC encompasses one of the most extensive efforts to acquire paleoseismic records, with over a dozen active paleoseismic projects in 2001, the integration of field and C-14 laboratory research is particularly beneficial in regards to improvements in research and cost savings.

Southern California 3D Structure from TriNet Surface Wave Data

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The three-dimensional S-wave structure was constructed for Southern California from Rayleigh and Love wave phase velocities, measured using teleseismic TriNet data. A two station method, using a spectral fitting technique through perturbations of S-wave velocity structure, was implemented to acquire the phase velocity measurements. This fitting technique was developed specifically for this project. The total number of paths used are approximately 3500 for Rayleigh waves and approximately 1500 for Love waves. New S-wave velocity maps exhibit some large-scale features that are more distinct than in previous tomographic results for Southern California. There is a clear seismic velocity contrast between the Pacific plate and the North American plate. The Pacific plate side is systematically faster than the North American plate side. The velocity contrast extends down to a depth of at least 60 kilometers. It is clear that this contrast penetrates below the Moho. In the northern part of our study area, the contrast in the upper mantle is fairly vertical and is almost exactly beneath the San Andreas fault. In the southern part of our study area, the contrast is underneath the Elsinore and the San Jacinto fault areas, west of the San Andreas fault. In the upper mantle, in addition to the well known fast velocity anomaly under the Transverse Ranges, there is another distinct fast velocity anomaly under the Peninsular and Coastal Ranges near the Southern extent of our study area. This velocity anomaly appears to be just as large as the velocity anomaly under the Transverse Ranges. Under the Eastern California Shear Zone, there are distinct crustal slow velocity anomalies, suggesting higher temperatures and lower viscosity in the lower crust. There are also slow velocity anomalies found under the Salton Trough and under the Southern Sierra region near the Coso area.

Lattice Particle Modeling of Earthquake Dynamics

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We consider earthquake faulting at the fundamental level of particle bond breaking and motion. Using computational lattice particle dynamic approach, high speed computers and visualization, we are investigating the earthquake dynamic rupture process and associated near fault ground motion under shear using in excess of 10^7 particles and both 2-D and 3-D models. In spontaneous rupture process observed from the foam rubber experiments, two of the most intriguing features are the earthquake fault separation during the rupture propagation and pulse-shaped slip motion with a partial stress drop. Our two-dimensional simulations show conclusively that a dynamic fault opening motion occurs as the rupture propagates along the fault in which a roughness specified for the fault surface. These results are consistent with the foam rubber experiments and could provide an explanation for the heat flow paradox. We also extend our lattice modeling to the thrust and normal faulting with and without sediment layers. For thrust faulting, we simulate earthquake faulting from 10^0 (shallow angle) to the 60^0 (deep angle). The steeper angle models are aimed at understanding ground motion in the 1952 Kern County earthquake as constrained by precarious rock surveys. Numerical simulations show that, due to the geometrical asymmetry of the thrust fault, the ground motions of particle velocities and particle accelerations on the hanging wall are larger than on the foot wall as the dynamic rupture reaches the surface. With a sediment layer involved in the foot wall, the ground motion on the foot wall is governed by a surface wave trapped in the sediment layer, and shows a small increase compared with that without sediment layer. For blind thrust faulting, we find that the particle velocities and accelerations on the foot wall are larger than that on the hanging wall. For three dimensional strike-slip faulting, the primary results show that the slip motions along the fault plane are strongly inhomogeneous and amplified particle occurs as the rupture reaches the free surface. The rupture process is more complex near the free surface. Fault roughness (amplitude and wavelength) and the particle interaction force law involved in the simulation governs many of the characteristics of the failure processes, such as the amplitude of the particle velocity, the size of slip and normal displacements, and the slip time.

The Dume fault, northern Santa Monica Bay, California

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We used industry seismic reflection and well data to create digital structure-contour maps beneath northern Santa Monica Bay. These maps include a principal strand of the Dume fault and a deformed horizon within the Pliocene Repetto Formation. This horizon is mapped 50 km from Pt. Dume westward to Port Hueneme and 20 km southward from the Malibu Coast-Santa Cruz Island fault across the Dume fault to the NW-striking faults and folds of the San Pedro system. The Dume fault dips gently-to-moderately north, and its hanging-wall is cut by the subvertical Malibu Coast fault. The overall strike of the Dume fault is to the west, but is arcuate, being north-concave on the east half of our study area and north-convex on the west. A W-dipping lateral ramp occurs within the WNW-striking segment. This lateral ramp coincides in space with the intersection of the Dume fault with a blind NW-SE Borderlands fault. The Pliocene horizon and the top Miocene volcanics can be correlated across the Dume fault and related fold, around its east and west plunges and also along its hanging-wall and footwall blocks. The interval between these horizons is thicker on the upthrown hanging-wall side of the fault, which is consistent with basin inversion. There is little shortening across the ENE-striking segment and over 3 km of shortening at the culmination of a double-plunging hanging-wall anticline along the WNW-striking segment. This anticline forms Sycamore Knoll and plunges abruptly west above the lateral ramp. The folding initiated during the Repettian Stage and accelerated towards the end of this stage. Preliminary kinematic analysis suggests that the Dume fault is predominantly left-lateral in its ENE segment. However, regional south dip in the hanging-wall of this segment represents 1-2 km of offshore structural relief in the Pliocene horizon. This relief may reflect a blind dip-slip component absorbed by folding at the scale of the Santa Monica Mountains.

1. The Dume and related sub-parallel/imbricate faults form a regional structure marking the southern deformation front of the Transverse Ranges.
2. Shortening is maximum along the WNW-striking segment of the Dume fault and slip is predominantly left-lateral along the ENE segment. A 700 m-high seafloor scarp along the restraining segment and seismicity to the east suggests that the long-term deformation continues during late Quaternary to present time.
3. Models for slip partitioning during transpression predict strike-slip on subvertical faults and thrust motion on parallel-striking low-angle faults. Our interpretation suggests strike-slip or oblique slip on both the low-angle Dume and the high-angle Malibu Coast fault. An additional blind dip-slip component is absorbed by any active folding of the Santa Monica Mountains.
4. The lateral ramp and doubly-plunging fold (dome) centered at the intersection between the Dume fault with a deeper blind NW-SE Borderlands fault suggests that both systems have been active during the late Quaternary.

The SCEC Borehole Instrumentation Program

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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 following three years. The long term scientific objectives of this program are: to estimate the degree of nonlinearity for strong ground shaking on typical Southern California soils; to improve our capabilities in predicting the effects of near-surface soil conditions on ground motions; and to examine the details of the earthquake source process.

The SCEC borehole instrumentation program is now nearing its end as the original SCEC sunsets and SCEC2 begins. Currently we have 8 sites operating with 6 of the 8 transmitting data to TriNet and the SCEC Data Center in real-time. By the end of year 2001 we plan to have 12 sites operational. All of the sites will eventually provide data in real-time to the Caltech/USGS Southern California Seismic Network (SCSN) or the California Division of Mines and Geology's (CDMG) California strong motion instrumentation program (CSMIP), or in near real-time dial-up mode the US Geological Survey National Strong Motion Instrumentation Program. The ability to get 12 sites when only enough funding for 7 was appropriated given SCEC budgetary constraints is due to the cost sharing and leveraging of funds in collaboration with multiple agencies, organizations, and programs. Of the remaining 2 sites to be installed, both have been drilled and cased and are ready for installation of the sensors.

Data from the first SCEC borehole instrumentation site, the Griffith Park Observatory became available on-line through the data center in September of 1998. Three sites, the Stone Canyon reservoir, the Wonderland Avenue School, and the Mira Catalina School became available on-line through the data center in the 1999 fiscal year. Another three sites in the San Fernando Valley at the Van Norman Dam Complex have cased boreholes that the USGS installed for site characterization. We plan to replace the current temporary borehole and surface instrumentation and make these permanent sites, incorporating them into existing TriNet stations already in place at VND. The Obregon Park site, a CDMG collaborative station is transmitting data in real-time to both CSMIP Sacramento and Caltech/TriNet and the downhole installation is scheduled for September 2001. Year 3 collaboration with the USGS and Water Replenishment District (WRD) led to the Long Beach vertical array (LBW-2,4). This site consists of two cased boreholes to GL-350 and GL-30 m depths. This vertical array will provide critical data on the soil behavior of a "typical" LA Basin site in both the small and large strain regimes as the waves propagate up through the soil column. Two downholes and surface instrumentation have been installed and are recording data locally on the dataloggers. The frame relay circuit for real-time transmission to SCSN is scheduled for install in September 2001. Two sites that were drilled and instrumented by the USGS previously, the Cerritos College (CER-2) and San Bernardino (SBF-1) arrays, will be upgraded to newer sensor technology and real-time telemetry to the data center installed as part of a SCEC/USGS/Caltech collaboration. The last site, Superstition Mountain, in the highly active Salton Sea region, has been drilled, logged, and cased as part of the ROSRINE effort. This borehole will be instrumented and connected to the NSMP station at that site before the year is out.

Borehole and surface observations from this project are used to calibrate the current numerical wave-propagation methods for predicting soil response. This data is also being used for development of new nonlinear modeling techniques for the behavior of soils under large strains. Using the borehole data as the input to our linear models, and the geotechnical site characterization data provided under collaboration with the ROSRINE project, we are able to reproduce the surface observations in the time, frequency, and response spectral domains for frequencies up to 10 Hz. The degree of non-linear behavior in California soils at large strain levels is a critical issue for determining the maximum plausible ground motions from large earthquakes. However, the lack of observed large-strain data from these new borehole sites in Southern California forces us to calibrate our nonlinear models with data from other regions, such as Japan until our new stations capture some moderate to large events.

3D Velocity and Density Model of the LA Basin and Spectral Element Method Earthquake Simulations

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We present a 3D velocity model and a 3D density model of the LA basin. We use the velocity and density models with a spectral element method (SEM) for simulation of seismic wave propagation, which is currently being implemented on a 156-node Pentium PC cluster at Caltech. Preliminary work shows that SEM results using a 1D velocity model for southern California compare very well to discrete-wavenumber results. Both the density structure and velocity structure must be defined in a 3D model for its use in simulations of seismic wave propagation with a spectral element method, to predict the distribution of hazardous ground shaking during large events. Previous work has typically used density values which were predicted by the sonic velocities and Poisson's ratios; use of our measured density values should provide more accurate ground shaking predictions, and comparison to previous results will provide a useful assessment of the importance of density as a parameter in such simulations.

The LA basin velocity model was constructed using sonic log and stacking velocity information, provided by oil industry sources and not previously incorporated into southern California velocity models. The density model is based upon a new database of approximately 300 oil industry density logs from across the Los Angeles basin. These logs use gamma ray emissions to determine formation density at samples of about one meter. We have developed an empirical relation between sonic velocity and density by comparing data from approximately 30 wells in which we have both velocity and density logs; for the remaining wells, we have derived relationships between depth and density. The density-depth and density-velocity relations will provide independent rules that can be employed to define density and velocity structure in areas where data does not exist, or in other areas with similar lithology to the Los Angeles basin.

Evidence for prehistoric coseismic folding along the Tsaotun and Chushan segments of the Chelungpu fault near Nan-Tou, Taiwan

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Although five large earthquakes in Taiwan have produced surface rupture during the last century, little is known about fault slip rates, recurrence intervals and spatial variations of fault displacement in Taiwan. The M_w7.6 1999 Chi-chi earthquake ruptured along previously unrecognized traces of the Chelungpu fault and has raised questions about potential sources of large earthquakes in Taiwan. The Chelungpu surface rupture is over 80 km long. It trends N-S along the western foothills of Taiwan, and is the westernmost active thrust fault with continuous surface expression resulting from east-west Philippine-Eurasian convergence. Vertical offset across the Chelungpu fault averaged 2 or 3 meters along the principal trace, but values as high as 5 and 6 meters were common along the northern 10 km. In order to characterize the prior rupture history along the Chelungpu fault, we are beginning paleoseismic studies along the Chelungpu fault. Paleoseismic and geomorphic studies along the southern Tsaotun and Chushan segments will determine spatial and temporal records of faulting on the Chelungpu fault. Two promising paleoseismic sites, near Nan-Tou, were chosen after examining aerial photographs that suggest prior fault scarps closely match the 1999 surface rupture. Here, vertical offsets average 1.5 – 2 meters along the principal trace of the fault. We report preliminary results of paleoseismic investigations across the 1999 surface rupture on the Tsaotun segment near Nan-Tou, Taiwan. Stratigraphic relations suggest folding is the predominant form of deformation in this region. Difference in the degree of tilt between buried paleosols across the fold scarp suggests prior coseismic folding. Termination of sandy units against continuous folded paleosols also supports prior displacement. Age constraints will be determined by AMS radiocarbon dating of detrital charcoal fragments that bracket the proposed event horizon. Coseismic folding and discrete fold scarp development along the Chelungpu surface rupture may well be analogous to future ruptures along the Sierra Madre fault, a range bounding thrust fault on the southern flank of the San Gabriel Mountains, or along reverse faults in Puget Sound, Washington. Such deformation pose substantial seismic hazards in these regions.

Late Quaternary Uplift Rates and Geomorphology of the Santa Fe Springs and West Coyote Folds, Los Angeles Basin, California

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We mapped Quaternary aquifers with water wells and 5 m DEM's from IFSAR to define rates of folding along the Puente Hills blind thrust system. A cross section across Santa Fe Springs along Carfax Ave suggests 100 and 165 m of uplift of the 330 ka Gage and 650 ka Lynwood aquifers, yielding uplift rates of 0.2 mm/yr between 330-650 ka and 0.27 mm/yr between 0-330 ka. For a 27° thrust, this yields a slip rate of 0.44 – 0.59 mm/yr. Surface folding is discernable across the Santa Fe Springs segment in the DEM, to a point 4 km west of the San Gabriel River. Aquifers correlated with reflectors in a USGS seismic profile along Carfax suggests lower relief for the Lynwood (85 m) and the Gage (59 m). We suggest the 1 km-long USGS profile images only part of the fold limb and that additional structural relief is accommodated further north, as defined by our subsurface mapping. Correlation of a shallow reflector in the seismic profile with the 15-20 ka Gaspur aquifer suggests Holocene uplift of 1.0 mm/yr. A similar analysis undertaken for the Coyote fold near Trojan Ave. suggests 85 and 229 m of uplift for the Gage and Lynwood, yielding uplift rates of 0.26 mm/yr between 0-330 ka and 0.45 mm/yr between 330-650 ka. Correlation of the Gage with a reflector on another USGS seismic profile along Trojan suggests equivalent uplift – (86 m), indicating the profile images the entire width of the Coyote forelimb at this site.

Interpretation of the LARSE II refraction cross-line data for the San Fernando Valley sedimentary basin

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In the second phase of the Los Angeles Regional Seismic Experiment (Oct. 1999, LARSE II), two auxiliary seismic profiles (line 3 & 4) were recorded in the San Fernando Valley (SFV). The lines are 11.5/22.5 km long and recorded 4/6 inline shots. The lines were designed to constrain the basin geometry and geology of the SFV in an effort to identify areas of potentially high seismic hazard.

Line 3 is located in the southern part of the SFV and strikes NW-SE through the Sepulveda flood control basin. Line 4 is located in the northern part of the Valley and strikes E-W from Hansen Dam to a point north of Chatsworth reservoir, crossing the Verdugo fault, the Northridge Hills blind thrust fault, and the Chatsworth reservoir fault.

The seismic velocity model for line 3 is based on tomographic inversion and has useful ray coverage to 2.2 km in depth. It shows a constant velocity gradient down to 1.5 km where the velocity reaches 4.0 km/s. In the southeast part of the line at 1.7 km depth, velocities of 4.5-5.5 km/s may identify crystalline rocks, as also reported from well data, and is also located north of the Leadwell high.

The velocity model for line 4 has adequate ray coverage down to 4.2 km. It defines a basin which deepens gradually from west to east, and terminates at a sub-vertical boundary in the east. This boundary is interpreted as the Verdugo fault. Velocity contours in the deeper western part of the profile, could represent the Chatsworth reservoir fault, but the ray coverage is relatively low. There is no evidence of the Northridge Hills fault, with the tomographic inversion. This could be because the profile crosses the fault at an oblique angle.

Universal Nucleation Length for Slip-Weakening Instability Under Heterogeneous Fault Loading

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We consider the nucleation of instability on a slip-weakening fault subjected to a non-uniform, locally peaked "loading" stress. That loading stress is the stress which would be sustained if there was no slip on the fault; it is assumed to gradually increase due to tectonic loading but to retain its peaked character. The case of a linear stress versus slip law, i.e., with a constant slip-weakening rate, is considered in the framework of two-dimensional quasi-static elasticity (in-plane or anti-plane strain) for a planar fault. Slip initiates when the "loading" stress first reaches the strength level of the fault to start slip weakening. Then the size of the slipping region on the fault grows under increased loading stress until finally a critical nucleation length is reached at which no further quasi-static solution exists for additional increase of the loading. That marks the onset of a dynamically controlled instability. We prove that the nucleation length is independent of the shape of the "loading" stress distribution. Its universal value is proportional to an elastic modulus and inversely proportional to the slip-weakening rate, and is given by the solution to an eigenvalue problem. That is the same eigenvalue problem as introduced by Campillo, Ionescu and collaborators for dynamic slip nucleation under spatially uniform pre-

stress on a fault segment of fixed length; the critical length we derive is the same as in their case. To illustrate the nucleation process, and its universal feature, in specific examples, we consider cases for which the loading stress is peaked symmetrically or non-symmetrically, and employ a numerical approach based on a Chebyshev polynomial representation. Laboratory-derived and earthquake-inferred data are used to evaluate the nucleation size.

USING GPS TO TRACK DISPLACEMENT OF THE PORTUGUESE BEND LANDSLIDE

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The subject of the study is the Portuguese Bend Landslide located on the Palos Verdes Peninsula in Rancho Palos Verdes, California. Located the south-western portion of the peninsula, motion along the 2.5 square mile landslide was triggered by the addition of fill for the extension of Crenshaw Boulevard in 1956. Block gliding occurs primarily on the Bentonite beds in a layer of the Portuguese Tuff within the Monterey Formation. In 1956, initial movement of the landslide ranged from 0.02 - 11 meters per year, which facilitated the destruction of over 130 homes located on the landslide. The Abalone Cove Landslide, just to the west of the Portuguese Bend Landslide, began movement in 1978 after a period of heavy rainfall. In 1980, the Abalone Cove Landslide Abatement District and Portuguese Bend Landslide Abatement District were created to consistently monitor and maintain the stability of the landmasses. Mitigation efforts included drilling wells for groundwater monitoring and the installation of a GPS network.

GPS data has been collected on average several times per year from 1994 to present for both land masses by Charles Abbott & Associates. There are 42 sites located on Portuguese Bend and 26 sites on Abalone Cove. Rates of vertical deformation on Portuguese Bend range from 0.5 cm/yr to over 70 cm/yr while Abalone Cove ranges from a less than 1 cm/yr to over 61 cm/yr. Horizontal displacement ranges from 30 cm/yr to over 400 cm/yr on Portuguese Bend and from about 1 cm/yr to nearly 4 cm/yr on Abalone Cove. In general, most rates of deformation increase with proximity to the coastline. Accelerated rates also occurred during a period of heavy rainfall in the 1997 - 98 El Nino winter.

Pressure solution strain and seismogenesis in an active compressional belt: The San Cayetano fault in the Transverse Ranges of California

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Pressure solution strain is a significant component of the total permanent (finite, inelastic) strain in the upper crust. It accumulates gradually and cannot be distinguished from elastic strain in geodetic measurements. Future seismicity may be overestimated based on geodetic measurements if pressure solution and other aseismic permanent strains are neglected. In order to evaluate pressure solution strain we examined structures in sedimentary rock within the Ventura Basin, in proximity to the San Cayetano thrust, a major active fault capable of large earthquakes. We distinguish three components of deformation controlled by pressure solution: 1) solution at clast or grain boundaries; 2) shortening along discrete cleavage planes; and 3) aseismic slip on small (gouge-free) faults. The direction of maximum shortening in folded strata tends to be horizontal for small faults but is bedding-parallel for grain-boundary dissolution and for cleavage. This suggests that different components of pressure solution strain dominate in

different parts of the compressional orogen or at different stages in the evolution of the orogen. A complex evolution of pressure solution phenomena is expected because each of the strain components is likely to respond differently to ambient conditions such as lithology or permeability. The orientations of structures formed by these mechanisms indicate N-S to NE-SW shortening directions, which are consistent with the active compressional tectonic setting and with current stress orientations. We measured 9-23% shortening from grain-boundary dissolution, 1-32% shortening from removal of material on cleavage planes and 2-8% shortening from slip on small faults. Grain boundary dissolution and cleavage were probably active in pre-folding and thus pre-faulting times and may presently be accommodating regional shortening in sub-horizontal strata of the Ventura Basin. Since small faults are concentrated along the master fault and accommodate current sub-horizontal shortening within the fault damage zone, these strains represent local, not regional values. Pressure solution activity may be coupled with changes in stress and fluid circulation during the earthquake cycle and may contribute to controlling the accumulation of elastic strain.

Dynamic triggering of earthquakes under slip-dependent friction

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The problem of earthquake triggering by dynamic stress waves is tackled. A finite fault of length L embedded in an elastic space is considered. A slip-dependent friction law is assumed. The fault is in a metastable equilibrium state and is perturbed by a propagating stress wave of sinusoidal shape, wavelength λ and amplitude *a*, both variable. As a general result, and in compliance with observations, it is shown that for a given fault and a given friction law, low frequencies are more likely to trigger the rupture than high frequencies. In a first step, let us consider the linear friction case, characterized by a non-dimensional weakening parameter ß. It is shown that the occurrence of triggering depends on the balance between the loading terms and the intrinsic mechanics of the fault. A threshold in frequency for the incident wave to trigger the rupture is revealed, which depends on the non-dimensional weakening parameter ß and separates a non-triggering domain with stable slip from a triggering domain with unstable slip. In the more general case of a nonlinear friction law, characterized by a varying non-dimensional weakening parameter ß(u), both wave's amplitude *a* and wavelength λ play a role in the occurrence of triggering. It is possible to define two different behaviors, depending on the friction law. Some faults exhibit a threshold in frequency to be triggered, while some other faults exhibit a threshold in amplitude. Considering the non-dimensional weakening rate ß(u) andβ_0 the universal constant of stability computed by *Dascalu* [2000], it appears that the two behaviors correspond to two types of friction laws. The faults which present a threshold in frequency are intrinsically unstable, that is their initial non-dimensional weakening rate ß(0) is superior to β_0 . On the contrary the faults which present a threshold in amplitude are intrinsically stable, that is initially $\beta(0) < \beta_0$. Under certain condition on the loading parameters and because of the non-linearity of the friction law, it exists a characteristic slip u_c for which $\beta(u_c) \geq \beta_0$. That is for a sufficiently large amplitude the fault may experience a transition from stability to instability and may be triggered. These results are independent from the shape of the perturbation and therefore also hold for a static stress increase. The numerical method is used to investigate the friction parameters of the 1980, Irpinia (Italy) earthquake.

Tectonic Geomorphology and Holocene Surface Rupture on the Chino Fault

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The Chino and Whittier faults serve as major sources of slip transfer from predominantly strike-slip rigid-block tectonics on the Elsinore fault in the south to folding and oblique-slip in the Los Angeles basin to the north. Paleoseismic studies on the Elsinore fault suggest a slip rate of 5.3-5.9 mm/yr and 2.5 +/-0.5 mm/yr on the Whittier fault. This suggests that 2.3-3.9 mm/yr of northwest directed strain is accommodated through faulting on the Chino fault and folding within the Puente Hills and Coyote Hills.

The tectonic geomorphology of the Chino fault indicates predominantly right-lateral strike-slip motion, based on northeast-facing fault scarps, saddles, offset ridgelines, deflected drainages, and beheaded drainages in the Chino Hills and northeast-facing fault scarps and vegetated lineaments in the alluvium near and southeast of Prado Dam. Clear deflections of the active drainages range from 25-100 meters whereas stream capture partially masks larger deflections of 400-500 meters. Right steps along the trace of the fault are coincident with embayments in drainage basins, suggesting local transtensional faulting.

A geotechnical trench placed across the principal surface trace of the fault exposed Puente Formation (Miocene) in fault contact with alluvium and buried soils. The vertical (N28W striking) main strand offsets the actively developing soil to within 1 meter of the surface. The base of the soil profile (BC1 horizon radiocarbon age 9,543 +/- 55 ybp) overlies but is not offset by a secondary fault, placing a maximum age of 9,598 ybp on the most recent surface rupture and a minimum age on the penultimate event. During the last event three soil boundaries were uniformly warped and vertically displaced (west side up) 15-25 cm. Underlying the active soil, a contact between an organic colluvial unit and a pebbly sandy clay loam (radiocarbon age 11,219 +/- 331 ybp) dips east and strikes orthogonal to the fault. Matching the apparent dips of this contact along the fault surface requires 4.2-5.6 meters of accrued right-lateral slip from two or more events in the last 11,550 years. Based on this data the average slip rate of 0.36-0.51 mm/yr on the Chino fault suggests that a significant portion of the slip budget must be accommodated on the Puente Hills and Coyote Hills structures.

RELM: Physical Models with Stress

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I am developing several maps of earthquake potential/earthquake probability in support of SCEC's Regional Earthquake Likelihood Models (RELM) program. RELM has asked its participants to generate a range of "well documented and physically defensible" models of earthquake rate density based on inputs from geology, seismicity, geodesy, and computer simulation. I offer three classes of earthquake potential maps – one based purely on geology, one based purely on geodesy, and one based on computer simulations of earthquakes on the fault system of southern California. Recent efforts have focussed on updating the computer simulation leg of the triad, partly as forward-looking response to the needs of SCEC2 where physically-based models of the southern California earthquake engine will be a priority. One major issue in these simulations is: How does one "wind-up" an earthquake machine in a self-consistent, physically plausible manner such that all the system faults keep their proper geological speed while not violating terribly, instantaneous geodetic data. Plying the bottom of the southern California crust with a spatially variable traction appears to be the best means to this end. Joint inversions of fault slip rate data and geodetic site velocities for the functional form of these bottom forces suggest that a moderately smooth shear zone-like pattern of traction increase with magnitudes of about 0.01 bar/year might suffice for my 2-D, elastic whole-space simulations.

The Road to Earthquake Early Warning-- A VSN Approach

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Progress has been made towards the goal of earthquake early warning in Taiwan. The concept of a virtual sub-network (VSN) is applied to the Taiwan Central Weather Bureau (CWB) seismic network – a 79-station, 6-component (3 velocity sensors and 3 FBA sensors) network employing direct digital telemetry with negligible transmission delay time. The earthquake rapid reporting time has been reduced to about 30 sec or less. This represents a significant accomplishment towards realistic earthquake early warning capability. The VSN system described here has been put into operation from December 2000 to June 2001. A total of 54 earthquakes (100% correct detection) have been detected and processed successfully during this period. Comprehensive earthquake reports are issued mostly in less than 30 sec, with an average of about 22 sec after the origin time. The 22 sec reporting time will offer more than 8 sec of early warning time to cities at distances greater than 100 km from the source, for which the shear-wave strong shaking arrival time is about 30 sec. This 8 sec is an adequate amount of time to carry out numerous pre-programmed emergency response measures prior to the arrival of strong shaking.

Evidence of Steep Faults in the Central Transverse Ranges From Seismic Refraction Data

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The recent LARSE II seismic experiment crossed the Central Transverse Ranges at a point north of the San Fernando Valley, CA. This experiment had both a dense receiver line (more than 1000 receivers with spacing of 100m to 500m) and a dense set of shots (approximately 100 shots with a spacing of 1km). In the Transverse Ranges, first arrival times, correlated over many shots, reveal the presence of 6 steeply dipping faults. The most prominent one of these is the Bouquet Canyon fault which separates the younger Vasquez formation on the south, from the Pelona Schist on the north. The seismic data indicates this is a south dipping fault, which when coupled with the observation that the motion is down to the south, indicates that the region was under extension in the recent past.

A full waveform modeling method was used to predict the effect of faults on the first arrivals. This was then used to locate the faults, as well as to determine their dips. The San Fransiquito fault, the Clearwater fault, and the San Andreas fault, as well as two buried faults in the Mojave desert were detected with this method. The seismic signatures of these faults are relatively small features and are only detectable by correlating over many shot points.

Unsolved Problems in the Los Angeles Metropolitan Area Based on Geology: Results of SCEC I

Robert S. Yeats, Oregon State University
Authors: James F. Dolan, Eldon M. Gath, Lisa Grant, Mark Legg, Scott Lindvall, Karl Mueller, Michael Oskin, Daniel F. Ponti, Charles M. Rubin, Thomas K. Rockwell, John H. Shaw, Jerome A. Treiman, Chris Walls, and Robert S. Yeats

We have compiled information about active faults in the Los Angeles metropolitan region, including the Los Angeles, San Fernando, east Ventura, and San Gabriel basins, as part of SCEC I. This summary leads to problems to be addressed in SCEC II. (1) The convergence rate across Los Angeles based on GPS, even when fluid withdrawals are taken into account, is larger than that based on geology, principally due to the slower than expected slip rate on the Sierra Madre fault. Sources making up the difference could include the San Jose and Puente Hill (at Walnut) anticlines, the Walnut Creek fault, and an anticline beneath the Whittier fault. (2) Late Quaternary slip rates commonly differ from longer-term rates (examples: Las Cienegas, Compton-Los Alamitos, and Whittier faults), pointing to the need for further work in late Quaternary tectonics. (3) Almost no progress has been made in determining late Quaternary recurrence intervals and slip rates on blind thrusts, although some initial efforts have begun at the leading edge of the Puente Hills thrust. (4) Offshore extensions of onshore faults (Newport-Inglewood, Palos Verdes, Santa Monica) as well as faults completely offshore need to be investigated, requiring different technologies than those employed in SCEC I. (5) Strain partitioning, in which major fault systems include both strike-slip and blind reverse-slip faults, is relatively unknown. Prime targets include the Whittier, Newport-Inglewood, and Palos Verdes faults. (6) A focused study is needed to obtain the dates of the most recent earthquakes, those of the late Holocene, including the 1769 earthquake recorded by Portolá, which could have originated in the San Joaquin Hills. The summary will be posted on the SCEC website as well as http://earth.geo.orst.edu/users/neotec

Living with Earthquakes in California: An Outreach Book

Robert S. Yeats, Oregon State University

This book was published in March of this year by the Oregon State University Press, with financial help from SCEC. It is designed as a one-term course about the California earthquake problem, including a history of earthquake awareness, introductory chapters on geologic time, plate tectonics, surface and blind faults, seismology, and geodesy, and chapters on earthquake forecasting, surface effects, tsunamis, earthquake insurance, government programs dealing with earthquakes from the federal to local level (including SCEC), home retrofitting, and individual and family earthquake preparedness. Issues driving current SCEC research are presented in a way that the general public can understand and appreciate. The book is ideal for a course integrating earthquake science, the technology of strengthening structures against earthquakes, and the societal response ranging from the involvement of government to earthquake insurance, including the CEA. The book is also useful as a reference for high school students and as a text for emergency preparedness personnel. Phone numbers and websites of agencies involved in earthquakes are included, a guide to preparation of term papers using the Internet. The book also includes a list of 142 important historical earthquakes in California and Nevada. The rationale is similar to that in *Putting Down Roots in Earthquake Country*, but is greatly expanded and includes all of California and Nevada. Copies will be available at the SCEC meeting.

Pollen Analysis of the Las Yeguas Paleoseismic Trench Site, Cholame Segment of the San Andreas Fault, California

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We used the identification of historic pollen from sediments at a paleoseismic site near Las Yeguas Canyon in south-central California (site LY4, Young et al., in review) to date the age of sediments disrupted by tectonic fracturing and the 1857 Fort Tejon earthquake. As part of our paleoseismic investigations at this site, sediments were collected for chemical extraction and identification of pollen grains to determine if historic pollen horizons existed in the soil column. We identified several exotic pollen types, which include *Salsola, Erodium,* and *Eriogonum.* Three pollen horizons have been identified within soil column of a fault-perpendicular trench. The oldest pollen horizon is approximately 1 m deep and is distinguished by the first influx of the youngest exotic species *Salsola* and a marked increase in other grains such as *Erodium, Liliacea* and *Eriogonum.* The lack of pollen grains preserved or deposited in sandy sediments at approximately 75 cm below ground surface could indicate a pollen horizon directly above the sample depth. The youngest pollen horizon at 40 cm depth is identified by the increase of most all pollen types and a decrease in degraded grains. The increase in the number of grains is likely because of better preservation of pollen in the younger sediments. This age is based on the timing *Salsola* was first introduced into North America and the degree of soil mixing. *Salsola,* often referred to as tumbleweed or Russian Thistle, was first introduced to North America in accidental shipments with flaxseed to South Dakota in 1873 (Kirkpatrick, 1992). Increased amounts of *Eriogonum Guttatum* has been observed in sediments disturbed by farming practices such as plowing. *Erodium,* or commonly called storksbill, is a geranium type weed and was first introduced into the American west by Spanish settlers in the early to middle 1700's (Kirkpatrick, 1992). With eventual dispersal of non-native plant species throughout dry regions of North America, their pollen grains have become incorporated into sediments like ours near Las Yeguas Canyon and used as historical index taxa. Because the sediments faulted in the last ground-rupturing earthquake are densely bioturbated, the age of the rupture cannot be tightly constrained with pollen analysis because of the vertical movement of pollen in the soil column. Fractures were observed from the bottom to within 20 cm below the surface of two fault-perpendicular trenches during the paleoseismic investigation at the LY4 site. The age of these fractures is constrained by the identification of historic pollen grains from layered sediments cut by the fractures. The age of layered sediments containing the youngest exotic pollen type, *Salsola,* are approximately 130 years old. The tectonic fractures observed at LY4 are the same age or slightly younger than the sediments containing *Salsola*, thus indicating that the fracturing could be related to triggered slip from a Parkfield event, such as the 1877 or 1881 earthquakes, or creep.

A Revised Chronology of Earthquakes Produced by the San Andreas fault at Burro Flats, near Banning, California

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Preliminary interpretation of relationships exposed in trenches across the San Andreas fault at Burro Flats suggests that the fault produced at least five earthquakes since about A.D. 500 (Yule and others, 1999 SCEC annual meeting; Yule and Sieh, 2001, GSA Cordilleran meeting). Calibrated radiocarbon dates on peat appear to constrain these earthquakes to A.D.1500-1850, 1400-1550, 1300-1450, 700-1100, and 450-800. Equivocal relationships exposed in the youngest layers do not preclude that an additional event or events may have occurred since about A.D. 1650. In addition, the ages that bound these earthquakes are not firm because many peats contain detritus, e.g., charcoal, wood, and/or seeds, and roots that could over- or underestimate the ages of the layers from which they were collected.

We have begun to radiocarbon date the bulk peat, flat-lying fibers, and detrital charcoal and/or seeds from each layer to establish a more precise chronology for earthquakes at the Burro Flats site. Fiber ages consistently yield the youngest radiocarbon ages, with bulk radiocarbon ages up to 130 years older and detrital charcoal and/or seeds 190 to 310 years older than the fiber ages. The flat-lying fibers are probably the decomposed remains of annual grasses or reeds that fell to the surface in winter, and we interpret the ages of the flat-lying fiber samples to most accurately record the layer's age of deposition. Radiocarbon ages from bulk peats therefore may represent 'mixing' ages that may be older than the age of deposition due to contamination by older detrital material. The fiber ages effectively compress the earthquake record at the Burro Flats site and are used to constrain the event chronology given below

During the summer of 2001, mapping of subtle faulting and growth strata relationships exposed by hand and back-hoe excavations in trenches 3 and 5 add support to previously considered equivocal evidence for two events since about AD 1650. These data, in combination with the fiber radiocarbon ages, suggest that the fault produced not five, but at least seven earthquakes since about A.D. 700; with each earthquake constrained to calibrated calendar ages of A.D. 1720-1850, 1650-1750, 1500-1620, 1450-1620, 1330-1460, 1000-1210, 700-1000.

Validation and modeling of earthquake strong ground motion using a composite source model

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Zeng et al. (1994) have proposed a composite source model for synthetic strong ground motion prediction. In that model, the source is taken as a superposition of circular subevents with a constant stress drop. The number of subevents and their radius follows a power law distribution equivalent to the Gutenberg and Richter's magnitude-frequency relation for seismicity. The heterogeneous nature of the composite source model is characterized by its maximum subevent size and subevent stress drop. As rupture propagates through each subevent, it radiates a Brune's pulse or a Sato and Hirasawa's circular crack pulse. The method has been proved to be successful in generating realistic strong motion seismograms in comparison with observations from earthquakes in California, eastern US, Guerrero of Mexico, Turkey and India. The model has since been improved by including scattering waves from small scale heterogeneity structure of the earth, site specific ground motion prediction using weak motion site amplification, and nonlinear soil response using geotechnical engineering models. Last year, we have introduced an asymmetric circular rupture to improve the subevent source radiation and to provide a consistent rupture model between overall fault rupture process and its subevents. In this study, we revisit the Landers, Loma Prieta, Northridge, Imperial Valley and Kobe earthquakes using the improved source model. The results show that the improved subevent ruptures provide an improved effect of rupture directivity compared to our previous studies. Additional validation includes comparison of synthetic strong ground motions to the observed ground accelerations from the Chi-Chi, Taiwan and Izmit, Turkey earthquakes. Since the method has evolved considerably when it was first proposed, we will also compare results between each major modification of the model and demonstrate its backward compatibility to any of its early simulation procedures.

Summary of Results of Crustal Structures Using Teleseismic Waveforms from LARSE

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Both the 1993-1994 and the 1998-1999 Los Angeles Region Seismic Experiments (LARSE-I and II) contained a passive recording phase in which a linear array of three-component short-period and broadband sensors were deployed along the active source experiment profiles. Although they represents a small portion of the whole experiment in term of budget, they produced large amount of waveform data from which detailed information about crustal structure can be derived. In this study, I use teleseismic P waveform, collected during the LARSE experiments, augmented by data from other permanent and temporary stations in the region, mostly the TriNet and the ANZA network. The analysis consists of three steps. First, I aligned all records from each teleseismic event on the first P arrival using cross-correlation. This gives us a very accurate measurements of teleseismic P delays across the whole area. It also lets me to obtain the effective source time function (STF) for each event by stacking all vertical records. These STFs are used in step 2 to compute teleseismic receiver functions. Finally, all radial receiver functions are migrated and stacked using the CCP stacking technique to generate crustal structure images. I show several crustal cross sections, including ones along the LARSE profiles. In these cross sections, we can see clearly sedimentary basins as well as deep crustal structures. For example, the results show that the San Fernando Basin and the Santa Clarita Basin extend to 6 to 7 km depth. The Mojave Block, at least the western and central part, has relative sharp and flat Moho discontinuity at a depth of about 30 km. But this feature is truncated, on both LARSE-I and II profiles, at the downward extend of the San Andreas Fault (SAF). Under the LARSE-I profile, a band of strong P-to-S conversions at depth range from 25 to 29 km suggests that the Moho beneath the San Gabriel Mtn. is shallow and the mountain ranges are supported dynamically by horizontal compression. Lower crustal structures along the LARSE-II profile south of SAF are very complicate as indicated by absence of Moho in some portions and several disconnected P-to-S conversions at depths from 30 to 40 km in other places. Combining regional tomography result and Bouguer gravity modeling, I suggest that lower crust there is composed of high-velocity/high-density material that is highly deformed by regional tectonics.