SOUTHERN CALIFORNIA EARTHQUAKE CENTER
NSF STC FINAL REPORT, 2/1/1991 to 1/31/2002

I. General Statement

The accomplishments of the Southern California Earthquake Center are best viewed through our vision statement as articulated in our original proposal (paraphrased as follows): "to develop the methodology for, and a prototype application of, a time and space dependent probabilistic **seismic hazard model** for southern California through multidisciplinary studies and integration of pertinent geoscientific information". This was referred to as the Center's "Master Model". The Center's accomplishments are all related to this vision or goal. They include the integrative aspects, or the whole, that directly address the overall goal of the Center, as well as the various parts that make up the whole within the disciplinary thrust areas. Moreover, all of the accomplishments, whether they be integrative or within disciplinary thrust areas, represent the outcomes of focused teams of scientists working in a fertile environment that would not have been possible without the support, coordination and organization of a center. Bringing together a critical mass of the nation's best earthquake scientists focused on a common goal opened doors, directed attention to earthquake research by potential end users, and afforded the opportunity for the scientific community to leverage considerable additional resources.

II. Integrative Science Accomplishments

Modeling can be considered in the context of software development. Moreover, as with software, complex models are particularly well-suited to collaboration. Software versions succeed one another as the level of sophistication and complexity grows; hence versions 1.0, 1.1, 2.0, etc. with which we are all familiar. In effect, one never achieves the ultimate goal. This is the approach we have taken with our seismic hazard models. Our goal to develop Version 1.0 was realized in three major integrative studies referred to as **Phases I, II, and III** (Version 2.0 is currently under development as part of an expanded, newly-funded study of the physics of earthquakes using southern California as a natural laboratory). The result of these studies, which spanned the entire 11 years of the Center, has been that SCEC, and the teams responsible for the studies, are now recognized as world leaders in the development and advancement of seismic hazard assessment methodology.

Phase I, entitled "Future Seismic Hazards in Southern California: Implications of the 1992 Landers Earthquake Sequence" was an in-house report developed jointly with the U.S. Geological Survey, the California Office of Emergency Services and the California Department of Conservation. It was the first comprehensive study to evaluate how a large earthquake might influence future earthquakes along major nearby faults – an important ingredient in seismic hazard analysis. The report noted that: 1) portions of the southern San Andreas fault appear ready for failure, and that where data are available, the time elapsed since the last large earthquake exceeds the long-term average, 2) since 1985, earthquakes have occurred at a higher rate than for the preceding four decades, 3) the M7.3 Landers earthquake is estimated to have increased the stress toward failure on parts of the southern San Andreas fault, and 4) Some aftershocks of the Landers earthquake sequence occurred near the San Andreas fault, while a few appeared to be within the mapped fault zone in areas where, typically, the seismicity has been relatively low. Major findings are as follows:

- The Landers earthquake increased the stress toward failure by up to 10 bars for the San Bernardino segment of the San Andreas, and less than 1 bar for the Coachella Valley segment, but decreased the stress toward failure by less than 1 bar on the Mojave segment (Figure 8 in report).

- Changes in failure stress up to a couple of bars also occurred on the somewhat more distant San Jacinto and Garlock faults.

- The increase in earthquake activity since 1985, including the Landers sequence, resulted (as of 1992) in an increase in estimates of the annual probability throughout southern California. The annual probability of a M7 or larger earthquake prior to 1985 was estimated to be about 4%. Following Landers, estimates ranged from 5-12%, depending on the effects of stress redistribution by the Landers earthquake and the ripeness for failure of the southern San Andreas fault. (Note: the nearby M7.1 Hector Mine earthquake occurred in 1999).

Phase II, entitled "Seismic Hazards in Southern California: Probable Earthquakes, 1994-2024" was published in the Bulletin of the Seismological Society of America (v. 85, No.2, pp.379-439, April 1995). This study, for the first time, combined geodetic, geologic (paleoseismic), and historical seismic information to estimate the frequencies of damaging earthquakes in a particular seismotectonic region – in our case southern California.

Estimates of seismic hazard (e.g., the probability of exceeding a prescribed intensity of ground motion over a given period of time) depend on knowledge of potential earthquake sources, seismic wave paths, and local site conditions. The Phase II report contributed to an improved understanding of the first of these factors. The earthquake source potential in each of 65 seismotectonic zones in southern California was estimated by combining geologic, geodetic, and historical seismic data. An up-to-date database of fault information including best estimates of the size and frequency of future earthquakes was generated. In addition the report summarized the historical record of earthquake occurrence. Finally, the report provided examples of seismic hazard estimates when the newly-derived earthquake source potential is combined with generic seismic wave path effects (attenuation relations) and local site conditions.

Phase II results were presented in terms of a preferred seismic potential model with lognormal recurrence and an alternate Poissonian model. The models predicted an 80 to 90% probability of an $M_W \geq 7$ earthquake within southern California before 2024. The January 17, 1994 $M_W = 6.7$ Northridge earthquake occurred within the 13% of southern California's area having the highest moment rate density, while the October 16, 1999 $M_W = 7.1$ Hector Mine event was an early realization of the 80 to 90% probability before 2024.

As an example of effect of the new Phase II source data on seismic hazard, the report calculated the probability of 0.2g or greater shaking before 2024 to exceed 60% in the Ventura and San Bernardino areas (realized in the case of Hector Mine), and 50% throughout the Transverse Ranges between Santa Barbara and San Bernardino (realized in the case of Northridge). Finally, it is important to note that the methodology and many of the results of Phase II were incorporated into the most recent version of the official seismic hazard maps of California produced jointly by the U.S. Geological Survey and the California Department of Conservation's Division of Mines and Geology (now the California Geological Survey).

As is often the case with major new technological advances of the scale of Phase II (i.e., Version 1.0), and perhaps just as important, the report raised more issues and questions than it resolved. In particular, the analysis appeared to predict future seismicity rates that were greater than that observed historically which would seem to imply one or more of the following: 1) the model underestimated the maximum magnitudes, 2) significant strain may be released aseismically, and/or 3) seismicity may have been anomalously low since the beginning of the historical record ca. 1800. However, a subsequent Center study was able to resolve this apparent discrepancy (Field, et. al, 1999). Other issues raised included the suitability of existing attenuation relations and site effect classifications for the southern California area, how to best estimate the maximum magnitude event on a given fault, and to what extent variations in the source model affect estimates of seismic hazard. These questions and issues led to Phase III ("Accounting for Site Effects in Probabilistic Seismic Hazard Analyses of Southern California"; published as 14 articles in a special issue of the Bulletin of the Seismological Society of America, vol. 90, no. 6B, December, 2000) and Phase IV (Regional Earthquake Likelihood Models – Version 2.0s; work in progress).

Phase III considered the issues of attenuation relations and site effects within the greater Los Angeles region. Specifically, the study determined the extent to which probabilistic seismic hazard analysis can be improved by accounting for site effects. It has major implications for future seismic hazard analyses and performance-based engineering design in earthquake country – specifically how to best estimate future levels of shaking at a particular site with the minimum uncertainty.

Given the somewhat arbitrary nature of the site-effect distinction (i.e., the separation of the site effects from the attenuation relation), Phase III defined the site effect as the response at a given site, relative to an attenuation relationship for a given intensity measure such as peak acceleration, averaged over all damaging earthquakes in a region. Moreover, the site effect should be defined as the average behavior, relative to other sites, given all potentially damaging earthquakes. A diligent effort was made in phase III to identify any attributes that predispose a site to greater or lower levels of shaking. The most detailed maps of Quaternary geology were not found to be helpful in predicting site effect amplification; either they were found to be overly complex in terms of distinguishing different amplification factors, or were judged inadequate based on actual strong-motion observations. However, the average shear-wave velocity in the upper 30 meters at a particular site was found to delineate significantly different amplification factors. Additionally, a correlation of amplification with basin depth also was found to be significant, with sites located above the deepest parts of the Los Angeles basin differing by up to a factor of two in amplification relative to sites in the shallowest parts of the basin. In fact, for the peak acceleration intensity measure, basin depth at a particular site was found to be more important than the 30-meter shear wave velocity. Figure 2 illustrates the combined effects of the 30-meter shear wave velocity and basin depth effects on site amplification for a portion of southern California. Despite these important site effects, the Phase III study found that the standard deviation of an attenuation relationship (i.e., the prediction error) is not appreciably reduced by making such corrections. This major conclusion suggests that our best hope for reducing such uncertainties will be through waveform modeling based on first principals of physics.

III. Accomplishments Within the Thrust Areas

Accomplishments within the thrust areas generally involved the participation of multiple investigators and integration at a somewhat more basic level. In essence, the thrust areas generated a series of more primitive integrative models that formed the basis for the Master Model. The following sections describe these more basic models within each of the thrust areas, and illustrate why a center mode of support and organization was necessary.

A. Fault Zone Geology Focus Group – Evidence for Earthquake Clustering

The 1992 Landers earthquake occurred within a broad zone of active faulting known as the Eastern Mojave Shear Zone. This zone branches off the San Andreas fault at the northern end of the Salton Trough, and carries about 15% of the Pacific – North American plate motion northward into the Great Basin of eastern California and western Nevada.

Shortly after the Landers earthquake, teams of scientists from SCEC and the USGS began a series of paleoseismic investigations within the Eastern Mojave Shear Zone to explore the history of earthquakes within the zone. The observations suggested that dextral, or right lateral, shear is distributed across the entire zone, with individual faults accommodating only a small proportion of the overall slip. Moreover, release of the regional strain appears to occur in temporal clusters of moderate to large earthquakes, with the 1992 event apparently the most recent in a sequence of late Holocene (0 to 1000 years before present) earthquakes that have ruptured nine faults within the Eastern Mojave Shear Zone. Previous clusters of seismicity were found to have occurred in the early (8000 to 9000 years before present) and middle (5000 to 6000 years before present) Holocene, and possibly the latest Pleistocene (~15,000 years before present).

The evidence for earthquake clustering in the Eastern Mojave Shear Zone is based on data from more than two-dozen trenches. The groupings during the past 10,000 years are fairly robust although errors for some of the paleoevents are substantial. However, it should be noted that not all events are necessarily of the same magnitude, and some earthquakes at different sites are probably the same event. Because events may differ is size, clustering was evaluated in terms of moment release that was estimated from the data at the various trench sites assuming rupture of the entire mapped fault length and a seismogenic depth of 13.5 km. Multi-segment or multi-fault ruptures were accounted for because moment was summed on a fault-by-fault basis. To estimate average slip, the analysis used information derived from either geomorphic studies of off set stream channels, 1992 slip measurements for faults involved in the Landers, or estimates derived from regressions based on fault length.

Moment release was evaluated according to a method that accounts for the inherent errors in dating prehistoric earthquakes. Moment release curves were generated for individual faults involved in the analysis. The shape of each curve was a probability density function where the error in event dating was accounted for by the shape of the function, and the area under the curve scaled to the moment of individual events on the fault in question (an arbitrary error of ±50 years was assigned to the 1992 Landers event). Finally, all curves were summed. A distinct pattern of clustering emerged that is robust for at least three cycles over the past 10,000 years.

Temporal clustering has also been observed in the seismically-active Imperial Valley, and may also be occurring along the western Sierra Madre fault system and northern San Fernando Valley. If clustering is a common phenomenon in southern California, then earthquake hazard models derived purely on the basis of Poissonian earthquake statistics will require serious re-evaluation. That is, time-dependent recurrence behavior will need to be more strongly incorporated into hazard estimates. One new approach that may assist in the analysis involves the way in quasi-static stresses are transferred between faults, or equivalently, from one earthquake to another.

B. Fault Zone Geology and Crustal Deformation Focus Groups – A Paradigm Shift in Earthquake Risk

Prior to the establishment of the Earthquake Center, it was believed that the San Andreas fault posed the principal seismic risk to southern California, even though the intensity of ground motions likely to be generated by a large event on that fault were poorly understood. The Center's "Master Model" focus, coupled with the occurrence of the Whittier Narrows earthquake in east Los Angeles in 1987, prompted a more comprehensive, multidisciplinary look at active faults within southern California, and in particular, within the greater Los Angeles metropolitan area. It was found that the network of so-called "urban" faults beneath the Los Angeles metropolitan area, many buried within the core of large crustal folds, because of their proximity to major population centers, were found to constitute a collective seismic hazard that is at least as great as that posed by the more distant San Andreas. Geodetic data from SCEC's Southern California Integrated GPS Network (SCIGN) has measured approximately 5 mm/yr of north-south convergence, or strain build up, across the Los Angeles basin.

An important emerging scientific result from Center research is the view that faults throughout southern California, including the urban fault network, and those of the Eastern Mojave Shear Zone and greater San Andreas System, act together as a mechanically integrated unit. Moreover, geological observations strongly suggest that strain throughout southern California is released almost exclusively by earthquakes on faults, indicating that aseismic fault creep and distributed, off-fault deformation associated with relative plate motions is insignificant.

The 150 to 200-year-long historic period in the Los Angeles metropolitan area has been an era of relative seismic quiet, with only 10-20% of the total elastic strain stored during this period having been released in earthquakes. This observation, coupled with the fact that virtually all of the accumulated strain is released in the form of earthquakes, implies a major lull in seismic activity in the region; i.e., there appears to be an appreciable amount of strain stored in the crust that must be released during future earthquakes. SCEC's paleoseismic investigations in the metropolitan region suggest that the bulk of this strain is often released during large $M_w \geq 7$ events – much larger than any events that have occurred on these faults in at least 190 years. A cluster of large earthquakes appear to have ruptured the Santa Monica, Hollywood, Raymond, and Whittier faults (all within the basin) 1,500 to 2,000 years ago.

In short, the Center set goals of understanding the mechanics of the Los Angeles basin's system of faults, and, in turn, converting that information into an improved assessment of seismic hazard. The Center organized multidisciplinary workshops to explore ways to achieve these goals, and to promote a focused observational effort where information was shared and objectives decided collectively.

C. Crustal Deformation Focus Group – The Southern California Integrated GPS Network and a First Generation Crustal Motion Model

While earthquake prediction is still a distant goal, realistic estimates of long-term earthquake potential are feasible and more practical. However, long-term seismic hazard estimation demands solutions to important scientific questions including where are the faults; how active are they; how large are the earthquakes they can produce; how likely are these earthquakes; and how does the earth's crust respond to them? New technologies including the Global Positioning System (GPS), Interferometric Synthetic Aperture Radar (InSAR) and a variety of different types of strainmeters have been used by SCEC to help answer these questions.

Most notably, SCEC, in partnership with the U.S. Geological Survey and NASA's Jet Propulsion Laboratory, expanded several small, disconnected arrays of permanent GPS receivers in southern California into an integrated 250-station network with a concentration in the greater Los Angeles metropolitan region. In addition to NSF, major funding for implementation of over 200 new stations came from the W.M. Keck Foundation, NASA, and the USGS. The network is referred to as the Southern California Integrated GPS Network or SCIGN, and is now regarded as the preeminent earthquake-related GPS network in the world. This innovative GPS Network tracks regional strain with unprecedented precision. This new network greatly improves our ability to assess seismic hazards, and quickly measure the displacements that occur during and immediately after earthquakes. The goals of SCIGN are to: (1) measure crustal movements throughout southern California that can be used to explore the important relationships between strain and earthquake potential, (2) identify blind faults and there level of activity in the Los Angeles region – SCIGN has confirmed ~8 mm/yr of convergence across the Los Angeles basin, (3) search for variations in strain rate that might precede an earthquake, and (4) measure the co-seismic and post-seismic response to major earthquakes. All of these goals have either been met or constitute ongoing research efforts.

SCEC's Crustal Deformation Focus Group generated three successive versions of a crustal motion model for southern California. The third and most recent version represented the first attempt to produce a unified horizontal velocity field from SCIGN and other geodetic data, showing contemporary interseismic deformation in the region. These data are on-line and can be accessed by any investigator to study patterns of deformation in any part of southern California, referenced to any permanent GPS benchmark or station. For example, one such study based on data from the Los Angeles basin suggests an alternative to the normally accepted process for accommodating convergence across the basin. Another study generated a regional strain rate model for southern California that showed a correlation between strain rate and occurrence of past earthquakes. Statistical analysis showed that the top 25% of the regions with the highest maximum shear strain rate experienced more than 70% of the M≥5 earthquakes between 1950 and 2000. Moreover, it was determined that the result cannot be explained purely by postseismic deformation, suggesting geodetic strain rate may have predictive capabilities with respect to long-term seismic potential.

SCEC scientists also used SCIGN to study crustal deformation during and after the 1999 M_w7.1 Hector Mine earthquake in the Mojave Desert northeast of Los Angeles. SCIGN had several stations in the epicentral region prior to the earthquake, and immediately following the earthquake, installed a number of new sites. Data have shown both co-seismic and post-seismic deformation in the months since the event. The co-seismic information provided an independent approach to characterizing the earthquake source, while the post-seismic data have been combined with survey-mode measurements and modeled as simple afterslip.

D. Earthquake Physics Focus Group – Static and Dynamic Stress Transfer Between Faults and Earthquakes

Before SCEC, a number of researchers had studied the problems of static and dynamic stress transfer. Studies in the late 1960's and 1970's by scientists from the U.S., Japan, and Poland provided evidence that static stress changes produced by a mainshock affected the spatial pattern of subsequent small earthquakes – specifically aftershocks. It was not until the occurrence of the 1992 M_w7.3 Landers earthquake in southern California, a year after SCEC began, that the scientific community started to fully embrace these findings. This occurred because three groups, all with SCEC ties, showed similar results for the stress-change impact of the Landers event. A related advance that occurred during that period led to an understanding of how great (M8) earthquakes can affect subsequent large (M7) earthquakes for decades – if not longer, and the appearance of a new geophysical term "stress shadow" that describes where earthquakes will not occur during a specified time period. SCEC researchers were able to demonstrate the tremendous effect that a great earthquake can have in reorganizing where and when future large earthquakes will occur. These scientific advances were enabled by SCEC's collaboratory nature, through its funding of workshops on the topic of stress changes, through the SCEC postdoc program, and through SCEC's ability to disseminate information to a broad range of researchers at its interdisciplinary, multi-institutional annual meetings.

Also prior to SCEC, the notion that earthquakes might propagate or cascade beyond steps and bends or "segment boundaries" in faults was not seriously considered. By 1991 (the beginning of SCEC) the first model of realistic dynamic stress transfer between faults during an earthquake was published. This theory was quickly justified by the occurrence of the famous 1992 Landers earthquake. In the region of Landers, earthquakes were anticipated to be M6 events, however the Landers earthquake instead cascaded from fault to fault and in rupturing over 70 km of faults, evolved into a M_w7.3 earthquake. SCEC encouraged the models of cascade earthquakes to be adopted by a number of communities, including the geology community, which has always seen faults as complex features, as well as by the community that produces earthquake probability estimates. The fact that earthquake ruptures can propagate from fault to fault or can jump across boundaries between segments radically alters estimates of seismic hazard since the effect is to produce larger, albeit fewer, earthquakes over a given period of time. Earthquake size, in turn, affects building codes and structural design, as well as earthquake preparedness and seismic safety. The interdisciplinary foci and collaborative nature of SCEC allowed rapid dissemination of a scientific idea with a practical outcome.

E. Earthquake Physics Focus Group – Spatial and Temporal Patterns in Regional Seismicity

Earthquake forecasting gained respectability with the development of plate tectonics which provides a rational explanation for why earthquakes occur where they do and gives an overall long-term recurrence interval of large events at plate boundaries. However, paleoseismological dating studies of prehistoric earthquakes have found that, while the average recurrence interval of large events agrees with plate tectonics, there is so much variability that useful short-term prediction is impractical. Moreover, the apparent lack of observable precursory phenomena has led to the general opinion that, even if they do occur, they may be specific to particular geological settings.

Over the past ten years under SCEC's Earthquake Physics focus group, a new approach to earthquake forecasting has emerged from a collaboration between seismologists and statistical physicists. From the perspective of statistical physics, the Gutenberg-Richter power law relation between earthquake size and recurrence interval is a natural consequence of the fact that the crust is in a state of “self-organized criticality”. In this view, plate boundaries are members of a class of uniformly driven non-linear systems that naturally evolve to a critical state and remain there. The critical state is characterized by stress correlation at all scale lengths up to the system size so that it is always possible for an earthquake to grow large. This class of models is represented by a cellular automaton in which an array of cells is randomly loaded at a uniform rate. When a cell is full, it transfers its load to its neighbors. If this causes one or more of them to be full, they transfer to their neighbors (including back to the original cell), and so on. Cascades of all sizes are always possible in this system and the cascades follow a Gutenberg-Richter like power law frequency-size distribution.

At first glance, self-organized criticality seems to rule out the possibility of earthquake prediction. If it is always possible for a small event to grow into a large earthquake, depending on where it happens to nucleate, then there is no rational basis for prediction. However, the cascade model may be a bit too simple for earthquakes in that it has little or no memory of past large events. A large cascade leaves the statistical distribution of stresses unchanged. The only energy loss associated with a large event occurs at the grid boundaries. For large events it decreases with grid size R as 1/R. This is why such systems remain in the critical state and why a large grid spanning event is equally likely at any time, and hence unpredictable.

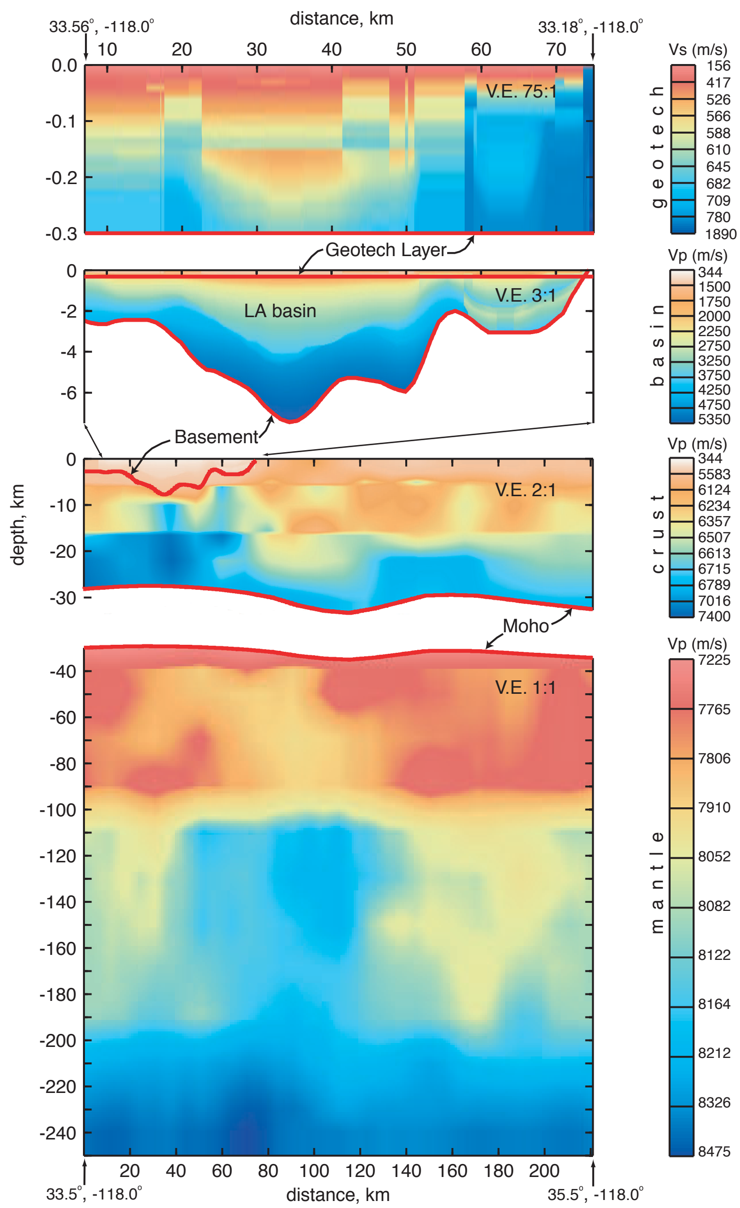
Over the past several years, SCEC scientists have found evidence that the crust remembers large earthquakes. Regional decreases in intermediate sized events have been documented lasting tens of years following large earthquakes. A corresponding regional increase of intermediate events has been observed in the tens of years preceding many large events. The increase in energy release rate associated with these intermediate events has been fit to a power-law time-to-failure equation, the expected functional form for a system approaching the critical point. The cellular automaton has been shown to systematically approach and retreat from the critical state if energy is lost during the cascade and/or if the largest events occur on frozen-in structures that approach the size of the system.

The critical point hypothesis for regional seismicity has been tested by showing that all earthquakes in southern California since 1950 with $m \geq 6.5$ were preceded by a period of accelerating seismicity. When the accelerating signal is optimized with respect to the size of the precursory region, a simple linear scaling relation emerges between the fault length of the event and the radius of the optimal region. Thus, SCEC scientists have laid the foundation for a new approach to earthquake forecasting base on precursory patterns in the regional seismicity itself.

F. Seismology Focus Group – An Integrated Seismic Velocity Model of Southern California

The major accomplishment of this group was to integrate geophysical, geologic, and geotechnical investigations to create the various generations of seismic velocity models. The different model versions are:

- Version 0: a prototype model that included the Los Angeles basin and the San Gabriel and San Fernando Valleys embedded in a 1D crustal model.
- Version 1: added the Ventura basin, Chino basin, and San Bernardino Valley, and revised the San Fernando Valley. This kept the same 1D crustal background model over a flat Moho.
- Version 2: included the Salton Trough, a 3D distribution of crustal velocities outside of the basins, a 3D Moho, and detailed shallow basin velocities from geotechnical logs.



- Version 3: added a 3D upper mantle.

This development sequence allowed a 'topdown' mode of model development, so that influences of shallower model components could be accounted for in building the deeper components. For example, the crustal contribution to teleseismic travel times could be subtracted from the data prior to performing the upper mantle tomography.

The velocity model development benefited greatly from the Center mode of support. The Center directly supported the model development as a complementary activity to the ground motion modeling. The velocity modeling activity grew out of the realization by the ground motion modelers of the utility of having such a model. Moreover, model use and support within SCEC allowed the model to grow enough for outside users to become aware of it. Once the model user base was established, SCEC provided a forum for model users to provide feedback in two ways – through extensive model validation efforts and forums for model users and builders to exchange views. In addition, the ongoing SCEC support and labeling of the velocity models as formal SCEC products allowed us to stamp the models with version numbers and establish them widely as useful reference models (for example, the 2002 NEHRP RFP calls out contributions to the CVM as a desired product).

Development of the velocity models (from Version 1 on) was overseen by an informal SCEC committee. Based on user feedback, validation modeling results, and data availability, we would decide on model additions and modifications that should be made. These ideas would be translated into specific proposals that were subject to the vagaries of funding decisions. Thus, while the model development was consistently supported, the specific aspects developed were not always in a logical sequence. For example, gravity modeling as a validation exercise was performed while incorporating independent density data was not supported.

G. Seismology Focus Group – Basin, Crust, and Mantle Structures in the Los Angeles Metropolitan Area

The greater Los Angeles region is an area of complex tectonics and laterally varying crustal structure. Moreover, many of the structures at depth are fault-controlled and directly related to the pattern of seismicity under and surrounding the Los Angeles region. Knowledge of the crustal and upper mantle structure, specifically the fault geometries and seismic velocities, is essential for estimating earthquake probabilities and accurately predicting earthquake ground motions.

In order to understand the regional structural framework, SCEC and the USGS combined efforts to conduct two principal seismic transects through the Los Angeles metropolitan region referred to as the Los Angeles Regional Seismic Experiments (LARSE), LARSE consisted of a series of active- and passive-source experiments designed to image the crust and upper mantle of the Los Angeles region with a focus on the Los Angeles basin and regional fault structure. The two transects extended from the offshore to the Mojave Desert – one passing trough the epicenter of the 1987 Whittier Narrows earthquake epicenter and the other through the 1971 San Fernando and 1994 Northridge earthquake epicenters. Over two hundred researchers and students from the SCEC community participated in LARSE field activities – a situation that would have had had little chance of occurring without the existence, resources, and coordination of the Center.

The transects confirmed that major decollements exist within the crust of southern California. These low-angle structures appear to link the series of more steeply dipping thrust faults that occur within the Transverse Ranges and Los Angeles basin into a complex structural system that may have important implications for the evolution of seismicity and seismic hazard in the region. For example, the Puente Hills blind thrust within the Los Angeles basin (site of the 1987 Whittier Narrow event) and the active Sierra Madre thrust along the southern flank of the San Gabriel Mountains sole into the same master decollement at middle crustal depths, which in turn, projects northward beneath the mountains and into the San Andreas fault.

LARSE scientific objectives and experimental research plans were carefully formulated via synergistic dialogue within the SCEC/USGS community. The SCEC Education and Outreach office provided substantial logistical support including preparing information fliers for the general public and city officials, as well as the time-consuming process of obtaining required permits from city, county, state, and federal agencies in a highly urbanized environment. Because LARSE was a multi-institutional NSF activity, community assistance and permits were easier to obtain than they would have been for any single institution or less ambitious activity.

H. Ground Motion Working Group – 3D Wave Propagation and Ground Motion Simulation

Three-dimensional wave propagation and its application to earthquake ground motion prediction stand out as one of SCEC's primary accomplishments. Successful development of 3D methods for wave propagation and their application has been a community effort. It had been recognized for some time that the three-dimensional structure of the Los Angeles basins was likely to be a significant component of attempts to compute ground motion from expected earthquakes. Moreover, the 1994 Northridge earthquake highlighted irregular patterns of ground amplification in sediments and near basin edges. Still, although the 3D structure of the greater Los Angeles area was well documented, the most advanced approach to propagating waves was limited to horizontally layered media. Developing reliable and verifiable methods for propagating waves in three dimensions became a high priority in SCEC. Simultaneously SCEC placed a high priority on developing 3D velocity models specifically for southern California with the highest priority on the Los Angeles basin.

The first 3D numerical simulations of ground motion in the Los Angeles basin combined Version 1 of the SCEC velocity model with a major earthquake on the San Andreas. This modeling effort showed that long-period surface waves would be generated at the basins' edges and would be amplified by the lower velocity sediments in the basins. In addition, the basins would prolong the duration of shaking. Later models have incorporated a series of improvements such that simulations from plausible future earthquakes are now becoming more representative of actual data. Improvements included 3D model development and code verification as discussed below, as well as improvements in the velocity structure discussed earlier, and the push to higher frequencies, principally through stochastic approaches.

The early models revealed that improvements were needed in both the velocity model and verification of the 3D computer codes, particularly if they were to be useful for engineering design purposes and seismic code development. In a group effort, SCEC scientists formulated a suite of numerical tests to ensure that the different numerical codes produced the same results, since there are significant numerical difficulties in simulating a realistic Earth structure. These include near-surface low velocity sediments, material attenuation, and proper averaging of material properties in a 3D structure. Although there were some initial discrepancies in the results, seven different codes have now converged and produce nearly the same results.

The uniformity in results is more than a numerical issue. The interaction between the faulting process and 3D structure leads to a complicated pattern of shaking that is believable only if one is sure that the wave propagation is correctly simulated. The SCEC community has used modeling of earthquakes in the Los Angeles area to make general predictions of the expected amplification throughout the Los Angeles area for earthquakes inside and outside of the basins. Conversely, ground motion recordings and 3D wave propagation become critical elements for understanding the nature of earthquake ruptures. The general approach to describe the kinematics of earthquakes comes from inverting low-frequency strong motion data using Green's functions that are based on layered models of the Earth structure. However, with the ability to propagate waves in three dimensions and having better 3D structural models, SCEC scientists are beginning to re-examine the data using 3D Green's functions. With better knowledge of the structure and increased capability for 3D wave propagation our understanding of the physics of the earthquake process will improve.

IV. Demonstration of National and International Leadership

A. Seismic Hazard Assessment Through Integration

SCEC's seminal Phase II integrative study and report brought several new dimensions to seismic hazard assessment methodology that have been adopted by the California Geological Survey and U.S. Geological Survey in the preparation of the most current state and national seismic hazard maps. Following presentations at international workshops (UJNR and ACES), groups in other countries including Japan, China, and New Zealand are following our lead.

B. SCIGN

The Southern California Integrated Network of permanent GPS stations is both a national and international leader in the application of GPS technology to the study of earthquakes. SCIGN's field installations, hardware, and data handling are being emulated elsewhere in the U.S. and abroad. One example is the "ray dome", designed by SCIGN and now standard on all installations. Orders are placed through SCEC that allows us to both highlight SCIGN/SCEC internationally as well as recoup the entire development cost of over $200K.

C. Interaction Between Earthquake Scientists and Engineers

SCEC initiated what many consider to be the most substantial, on-going dialog between scientists and engineers on what aspects of seismic hazard (ground motion) are required by engineers in performance-based seismic design.

D. Outreach to Practitioners

SCEC's Education and Outreach focus group has connected SCEC researchers to practicing geotechnical and structural engineers, engineering geologists, and public officials from throughout California and in Japan, Italy, and New Zealand. Interactions have occurred via numerous workshops and individual presentations.

V. Education, Public Outreach, and Knowledge Transfer

Since SCEC’s inception as a National Science Foundation Science and Technology Center in 1992, its leaders and outreach professionals have learned that effective, two-way communication is the first and most important step to establishing stronger ties between researchers and the public. We have learned that interpretation of scientific research - reducing results to understandable, usable products that improve hazard awareness, public safety, and mitigation efforts - is an essential part of the application process. Finally, we have learned that successful communication between scientists and the public is usually the result of each group sharing responsibility for active and continuous collaboration.

SCEC Communication, Education and Outreach (CEO) long-term goals were:

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

SCEC's CEO program pursued four main objectives:

- Build upon student and public interest in the natural environment,
- Utilize the scientific and educational expertise of SCEC in outreach and knowledge transfer,
- Expand access to earthquake information via the Internet and other media, and
- Foster a greater public understanding of earthquake risk.

A. Knowledge Transfer

SCEC has become one of the main conduits for earthquake education and mitigation information in southern California. The Center's work with the Seismic Safety Commission, California Division of Mines and Geology, and the City of Los Angeles, for example, is strengthening the resolve of public officials to improve mitigation strategies such as sponsoring new seismic safety legislation, improving hazard maps, and strengthening seismic ordinances. Earthquake scenarios being developed by the SCEC are providing much more realistic estimates of future ground shaking in the metropolitan areas of southern California that can be used for engineering design and upgrading seismic codes.

SCEC’s knowledge transfer program has emphasized activities that promote two-way communication while providing participants a variety of ways to stay in touch with the researchers and the results of their efforts. These have included:

- Frequent science/engineering seminars: Featuring state-of-the-art ideas, methods or hypotheses, these promote lively exchange among researchers. Although seminars primarily target scientists and engineers, we invite practicing professionals with expertise in applying the research.

- Technical Briefs: Distribution of research results, in a form ready for application by professionals, should include recommendations for how to use the information in practice, as well as describe the limitations of the results.
- Field excursions: In earthquake research, field studies are not only a necessity but also an excellent means to transfer knowledge to other researchers and to end users.
- Informational and/or Technical workshops and/or short courses: An excellent way to transfer scientific or technical information to end users with specific needs. These programs promote two-way communication and often stimulate innovative ideas for new approaches in solving problems. Participants contribute abstracts or papers for proceedings and technical briefs.
- Publications (newsletters, articles or papers in other organizations' publications, Web sites): These tools can significantly impact the community-at-large, provided the expertise and energy level of the knowledge transfer professional matches the resulting increase in public demand.
- Agreements, Alliances, Partnerships, and/or Links to groups in the research and user communities. Successful linkages require participants who have knowledge of system processes, have a high tolerance for ambiguity, accept the high transaction costs associated with interdisciplinary activities, and are able to overcome communication problems by developing a common language.

Examples of knowledge transfer products and activities include:

- **City of Los Angeles Seismic Zonation Workshop**. In 1995 and 1996, SCEC conducted a workshop on zoning for Los Angeles area earthquake risks. The workshop included two days of presentations of the latest scientific data on earthquake hazards in the City of Los Angeles and surrounding municipalities, and discussion of engineering and mitigation issues, including seismic zoning and code requirements. The workshop was held in response to a Los Angeles City Council resolution, which called for a workshop on the question: "Given our knowledge of the earthquake hazard in the City of Los Angeles and contiguous municipalities, does more detailed seismic zonation make sense?" The workshop was well attended by over 250 participants from government, academia, and practicing professional communities. A full report was produced and is available through SCEC Outreach.

- **Joint Task Force.** One outcome of the City of Los Angeles Zonation workshop was the formation of a joint task force to continue studies of vulnerable structures in the region. This gave rise to a project conducted by the City of Los Angeles / Structural Engineers of Southern California / SCEC Ground Motion Joint Task Force (JTF), to bridge the gap between earth scientists and engineers regarding earthquake hazard and mitigation. The task force was made up of structural engineers, civil engineers, geotechnical engineers, building officials, planners and earth scientists. They provided recommendations to the Los Angeles City Department of Building and Safety regarding earthquake ground motion hazards (specifically liquefaction and landsliding). The information in their reports will be used to determine public policy related to design of new buildings and seismic retrofit of existing structures (such as "tuck under" parking buildings).

  - Liquefaction hazards were addressed by one subgroup of the task force made up of engineers and geologists with academic, practicing, and regulatory backgrounds. They produced a new document published by SCEC, called "Recommended Procedures for Implementation of DMG Special Publication 117 - Guidelines for Analyzing and Mitigating Liquefaction Hazards in California." The report is intended to help engineers, geologists and building officials competently evaluate and take protective measures against the potential liquefaction hazard in many areas of southern California.
  - Two workshops on use of the liquefaction report were conducted by SCEC for city and county officials and consulting engineers. The full-day workshops included a chapter-by-chapter overview of the material, and ample time for discussion and feedback.
  - A similar Landslide Hazards implementation report was published in spring, 2002 and two explanatory workshops are being offered, similar to the Liquefaction document and workshops.

- **Real Meaning of Seismic Risk.** A series of symposia and workshops that focus on urban seismic risk issues. Feature a lively, compelling exchanges among earth scientists, earthquake engineers, building officials, public policymakers, architects, insurers, developers and the media. The first symposium was conducted in October 1999 in partnership with Los Angeles County Urban Search and Rescue and the LA City Emergency Planning Commission, who sponsored the event. About 100 people attended the daylong symposium. The second workshop was held in June 2000. Once again, EPC provided the venue. The topic was "Earthquake Preparedness for Schools," and was attended by teachers and administrators in K-12 schools as well as police and fire officers who respond to earthquakes and other incidents. A third workshop in November 2000 repeated the "Earthquake

Preparedness for Schools" symposia in another region of Los Angeles County.

- **HAZUS Improvement and Implementation.** The objective of SCEC's HAZUS (FEMA's earthquake loss estimation software program) project are to:
    - improve the earth science inputs (attenuation functions, soil maps, etc.) used by HAZUS to calculate ground shaking by forming a committee of scientists, engineers, and HAZUS programmers to recommend needed revisions.
    - foster implementation of HAZUS by governments, corporations, and consultants.

  To accomplish these objectives, 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. To date SCEC has organized three SoCalHUG meetings and 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.

B. Public Outreach

- **Putting Down Roots in Earthquake Country**. To answer the growing concern regarding the implications of the Northridge earthquake and other recent seismic events in southern California, the U.S. Geological Survey and SCEC produced and distributed two million copies of this graphically illustrated, 32-page color publication. Its message is consistent and encouraging: earthquakes are inevitable, but they are understandable, and damage and serious injury are preventable. This publication has been the basis for a Nevada version (substituting Nevada earthquake information but keeping the preparedness and earthquake basics sections).

- **SCEC's main 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.

- **SCEC Data Center** (www.scecdc.scec.org). This resource made an important contribution in putting the earthquake catalog, phase data, and seismograms online for the research community. Beyond the research use of the data center are its public uses- earthquake magnitudes and locations are available within minutes of any earthquake in southern California on the recent earthquakes web page (http://www.scecdc.scec.org/recenteqs/) that receives millions of visitors after larger earthquakes.

- **SCEC InstaNET News.** The objective of this service (now known as "SCEC News") is to provide rapid and routine distribution of SCEC news, earthquake information, and in-depth coverage of earthquake research. SCEC InstaNET is prominently featured on the SCEC Webservice Home Page; articles relating to research will be located on both the research pages and in the "News Service" section of the site. Links to resources, related information, and other sites will be added where appropriate. A brief news "byte" is written for each article added to the I InstaNET web pages. These bytes are e-mailed to subscribers of the SCEC News listserv. After each "byte:" a link to the complete articles is listed.

- **SCEC Quarterly Newsletter.** Replaced in March, 2000 by SCEC InstaNET News, this printed newsletter featured contributions by SCEC scientists and working group participants; regular editorial(s) by the Center Director and Science Director; a compilation of currently available resources, published materials and databases, with instructions on access; a "Fault of the Quarter" featuring latest research results on southern California selected faults; a "SCEC Researcher of the Quarter" section featuring interviews with selected SCEC scientists and/or engineers; and one or two reports on interesting or exciting research results. Recipients of the newsletter include principal end users of SCEC products (disaster preparedness officials, practicing design professionals, policy makers, California (and beyond) business communities and industries, local, state and federal government agencies, the media, and the general public), and members of the educational community.

- **Palos Verdes Peninsula Field Trip Guide.** A lively narrative on a number of sites at which to observe fossils, rock structures, and look at faults. It's also the only publication in print which offers a six-page easy-to-read geologic history of the Los Angeles basin area. Two foldout maps are included.

- **Palos Verdes Fault Guide.** Designed for engineers, geotechnical professionals and earth scientists. Unlike the broad information provided in the Palos Verdes Peninsula field trip guide, this guide focuses on the Palos Verdes fault. Included is a discussion of the fault as a whole as well as information pertaining to the many sites along the route. Recent studies have shown this fault to be more active and hazardous than previously believed.

- **Newport-Inglewood and Whittier-Elsinore Fault Zones Guide.** Rather than offering a route to follow for a field trip, this guide discusses the two fault zones, allowing the reader to design his or her own trip. Emphasis is placed on the methods scientists use to learn about faults, such as trenching.

- **EqIP.** SCEC CEO 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, 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 initial development of EqIP's website which provides a database of descriptions of over 250 organizations with links to their websites. SCEC’s Director for CEO is now the Chair of this group.

- **Media Relations.** SCEC has successfully engaged local, regional and national media organizations (print, radio and television) to jointly educate and inform the public about earthquake-related issues. The goal has been to communicate clear, consistent messages to the public–both to educate and inform and to minimize misunderstandings or the perpetuation of myths. SCEC CEO encouraged scientists who are interested in conducting interviews with media reporters and writers to take advantage of short courses designed and taught by public information professionals.

- **Care and Prepare.** KTLA-TV in Los Angeles partnered with SCEC to produce a streamlined version of *Putting Down Roots in Earthquake Country*, titled *Care and Prepare,* which was produced in both English (1.5 million copies) and Spanish (.5 million copies) and distributed through McDonald's restaurants throughout southern California in April, 1999. 500,000 children's versions were also produced. This was part of a media campaign for Earthquake Preparedness month that included live interviews with SCEC scientists during the morning news program and half-hour specials in the evening.

- **LA Underground**. Pre-recorded commentaries aired on KFWB radio in Los Angeles and featured SCEC scientists and researchers in one-minute segments.

- **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 attended), 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)

- **Los Angeles Region Seismic Experiment (LARSE).** For LARSE I and II, SCEC CEO managed the permit process, coordinated press releases, distributed *USGS/SCEC LARSE II fact sheets*, met with government officials, made public presentations, and represented the project to the media. Both studies received national and international news coverage.

- **ANNA-SCEC Neighborhood Awareness Program.** In 1998, SCEC conducted a yearlong program to raise awareness and educate homeowners in the inner-city Adams-Normandie Neighborhood Association (ANNA) on planning, preparation and mitigation methods. The program included presentations by scientists on LA urban earthquake hazards, a preparedness survey, provision for installation of automatic gas shut off valves, and a neighborhood earthquake safety fair. We produced a report that features a guide to communities for earthquake preparedness. A paper on the project was published in ASCE's *Natural Hazards Review,* February 2001.

- **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, located on the Carrizo Plain – a 3-4 hour drive north of 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.

C. Education

- **SCEC Undergraduate Internship Program.** To provide hands-on experiences in the earth sciences, provide insights into career opportunities, and interest underrepresented undergraduate students in Earth science-related careers, SCEC funded 72 students to date (including 39 women and 16 minority students) to work alongside 50 SCEC scientists. In addition too their research, the interns attended a Communication Workshop held jointly with interns from the Pacific Earthquake Engineering Research Center (PEER), participated in a field trip to geologic points of interest and research facilities in southern California, led by SCEC scientists, and presented posters at the SCEC annual meeting.

- **ShakeZone Museum Exhibit.** SCEC 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 ("ShakeZone") in their region. The mission of the exhibit, which opened January 17, 2002, 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 presents information about science, engineering, safety and mitigation. A shake table, an interactive computer display, and wall displays teach the visitors about the tools and techniques of earth scientists, engineers and emergency services personnel.

- **The San Francisco Exploratorium's *Faultline* Project.** Featured live remote interviews with SCEC scientists at research sites along the San Andreas fault. See www.exploratorium.org/faultline/.

- **USGS/SCEC/IRIS Teacher Education Workshops.** On November 17th, 2001, the Southern California Office of the U.S. Geological Survey and SCEC held an earthquake education workshop at Polytechnic School in Pasadena, CA. The workshop explored the science of earthquakes and applied those concepts to a wide range of activities. The Incorporated Research Institutions for Seismology (IRIS), provided curriculum materials, posters, books and many of the supplies for the workshop. The objective of the workshop was to present educators with earth science and earthquake materials and activities that they could take back to their students. This was the first of many planned workshops.

- **Seismic Sleuths Revision.** SCEC has revised 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.

- **Earthquakes: Seismic Sleuths.** This companion television special based on the *Seismic Sleuths* curriculum was 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.

- **SCEC's Regional Seismicity and Geodesy Web education modules.** These online learning resources are based on data from the SCEC data center and SCIGN network, and are used by high school and basic under-graduate students and teachers.

- **Electronic Encyclopedia of Earthquakes.** This collaborative project between SCEC, CUREE and IRIS is synthesizing a large and varied amount of data and information, and providing broad access via the Internet in the context of the Digital Library for Earth System Education (DLESE). The subject matter features earth science as well as principles of 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 framework for the Encyclopedia has been developed and the content collection process is on-going.

VII. Partnerships

Partnerships have been a hallmark of SCEC since its inception. Linkages have been greatly strengthened between campuses through our Board of Directors (consisting of one member per core institution), our shared facilities, and our focus groups. Graduate students have been among the most important contributors to these partnerships, having savored the many opportunities (e.g., workshops, symposia, annual meeting) provided by SCEC for interactions with faculty and students from institutions other than their own. For example, the poster session at the SCEC annual meeting, and the annual meeting itself, were places where many fertile student/faculty interactions took place, strengthening the collaboration between campuses.

Significant partnerships have developed with the U.S. Geological Survey and the California Geological Survey – both end users of, and partners in, SCEC research. NASA's Jet Propulsion Laboratory has been a critical partner in the development of SCIGN.

The City and County of Los Angeles have partnered with SCEC in reaching out to the southern California community to communicate new research results related to regional earthquake hazards.

SCEC has not been successful in developing partnerships or collaborations with minority-serving institutions and/or women's colleges, perhaps due to the relative dearth of such institutions in the southwest. Even with our core institutions, SCEC has found it difficult to maintain substantive interactions at arms length.

VIII. SCEC Shared Experimental Facilities

The scientists in the Southern California Earthquake Center shared several experimental facilities. Data is available to all researchers in the center and the broader scientific community on the web (through www.scec.org). It was the policy of SCEC to make data available to academic and government scientists without cost. The SCEC shared facilities are described below:

A. Earthquake Data Center.

The SCEDC is the primary archive facility for seismic information for Southern California earthquakes. The data archive consists of earthquake parameters and travel time picks from 1932 to the present, waveform recordings from 1981 to the present recorded by the Southern California Seismic Network (SCSN) and Caltech-USGS TriNet, SAR satellite images of Southern California, and some regional refraction profiles of the crust and mantle. Data from portable instrument deployments after the 1992 Joshua Tree and Landers earthquakes, as well from the 1994 Northridge earthquake, are also stored in this facility. The Data Center is currently archiving nearly 3000 data channels from 375 stations. An average of 20,000 earthquakes are processed and archived each year.

The SCEDC facility was initiated in October of 1991 as part of the Southern California Earthquake Center (SCEC). The several thousand computer tapes of the Caltech/USGS Seismic Processing (CUSP/SCSN) archive were translated into a custom ASCII database containing parametric earthquake data. The triggered seismograms for over 300,000 earthquakes were stored on an internet-accessible 0.6 Tbyte optical WORM mass-storage system. The user access to this archive was initially through direct login to the Data Center machines. Parametric data (e.g. hypocenters and phase picks) were later made available through a web interface (www.scecdc.scec.org/catalog-search.html). Until late 1999 when TriNet, the new modern digital broadband array (Hauksson et al., 2001), came on-line, the SCEDC archive consisted primarily of short-period, 100 sample/second waveforms from the SCSN. Since September of 1999 the data center archive contains waveforms from over 150 broadband and 200 accelerometer instruments, as well from the original SCSN short-period vertical stations. Data transfer between the monitoring network and the Data Center has also changed significantly since its inception. A time delay of a few days used to be the standard for new data to be available at the SCEDC. With the inception of the TriNet system and with changes in the daily operations and daily archiving of the Data Center, new earthquake data are available to the community in near real-time.

The Data Center is being accessed by both scientific users and the general public, with web access from the *com*-domain dominating the counts. In 1998, for example, the Data Center was sustaining approximately 500,000 hits per month with 70% of these from *com* and 30% from *edu* and *gov* domains. Since 1998, the use of our on-line waveform archive tool has invalidated "hits" as a useful measure of number of users. Of the users that have research accounts with the Data Center, 34% are from the SCEC core institutions, 50% are from other US institutions, and 17% are from foreign organizations.

Data archived at SCEDC have been used in numerous scientific studies that are associated with SCEC and by studies that are outside of SCEC. The SCEDC data contributed to research in the areas of local earthquake studies, regional and global earthquake studies, crustal structure and properties, earthquake patterns, coda Q and scattering, and state of stress in the crust. A quick scan of the SCEC bibliography database indicates that data archived by SCEDC has contributed significantly to some 60 papers in the list[1], and in some capacity to numerous others. There are also a significant number of publications using the data that are not listed in the SCEC publications database.

B. GPS Networks.

Southern California now benefits from a state-of-the-art geodetic array for monitoring earthquake-related crustal deformation, as the result of SCEC's vital coordinating role. The innovative Southern California Integrated GPS Network (SCIGN) tracks regional strain with unprecedented precision. This new network greatly improves our ability to assess seismic hazards and quickly measure the larger displacements that occur during and immediately after earthquakes. SCIGN stations receive radio signals from GPS satellites, and scientists use the data to observe motion on active faults, and to better assess earthquake hazards. Compression along the San Andreas fault's "Big Bend" squeezes the Los Angeles region, pushing up the San Gabriel Mountains. SCIGN data record this slow strain buildup. SCIGN has advanced high-precision GPS technology and is applying it to improve assessments of earthquake hazards in southern California. In coming decades, large earthquakes will certainly strike this region, where millions of people are at risk. SCIGN data will help in reducing the loss of life and property by

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[1] The following publications listed in the SCEC database have used data archived at SCEDC
10, 12, 14, 22, 26, 27, 29, 30, 31, 32, 34, 49, 53, 54, 55, 57, 58, 66, 69, 74, 77, 91, 97, 100, 111, 112, 114, 120, 123, 124, 125, 129, 131, 135, 138, 141, 142, 146, 147, 157, 158, 178, 179, 180, 214, 215, 226, 239, 260, 287, 293, 324, 337, 341, 363, 370, 371, 414, 452, 488, 489, 491, 493, 460, 475, 490, 517, 541, 543, 553, 554, 575.

providing a better understanding of the earthquake hazards. Scientists of organizations participating in the Southern California Earthquake Center (SCEC) designed and manage SCIGN. The U.S. Geological Survey (USGS), NASA's Jet Propulsion Laboratory (JPL), and the Scripps Institution of Oceanography at the University of California at San Diego are the main participants in SCIGN. In addition, land surveyors founded the California Spatial Reference Center to help their community use GPS data and to build on and sustain SCIGN and other networks. Funding for SCIGN is provided by the W. M. Keck Foundation, the National Science Foundation (NSF), NASA, and the USGS.

C. Portable Broadband Instrument Center.

The SCEC Portable Broadband Instrument Center (PBIC) http://www.crustal.ucsb.edu/scec/pbic/ was one of the highest infrastructure priorities since the inception of SCEC. There had been a recognized need in SCEC for its scientists to have access to instruments for focused studies as well as recording of aftershocks should a significant earthquake occur. Looking at the experience of the IRIS PASSCAL program, SCEC bought digital recorders and coupled them with both accelerometers and velocity transducers to cover the full range of possible ground motion recording needs. Over SCEC's lifetime the recorders were continually upgraded with GPS receivers, more RAM, larger disks for longer recording times and satellite telemetry for querying the status. As it became apparent that longer period waves were critical in basin analyses, the PBIC invested in a limited number of longer-period sensors. In SCEC's history the PBIC instruments have been deployed immediately following earthquakes: 1992 Joshua Tree, 1992 Landers, 1994 Northridge and 1999 Hector Mine. They have also provided critical data for the LARSE experiments and numerous site amplification studies. These instruments have provided SCEC scientists with exactly the advantage they needed to undertake individual and collective experiments that have furthered our understanding of the structure of the crust, sediment amplification, the structure of fault zones and the nature of mainshocks. Though the number (18) of SCEC recorders is not large, they have validated SCEC's investment in a pooled resource that is maintained for the benefit of the entire community.

D. Strong Motion Data Base.

SCEC initiated the strong motion database (SMDB) in 1992 in order to provide its scientist with rapid access to the California strong motion data so critical to understanding both the earthquake process and to seismic hazards. Prior to SMDB the strong motion data were accessible only by event; however, as the number of recordings grew, it was apparent to SCEC that the accelerograms had to be retrievable not as entire groups associated with a particular earthquake but as individual records that were pertinent to each user's needs. While the first database was established with internet access, it was apparent that in order to provide this database to a wider group of scientists and engineers the database had to become web based. In 1997 access to the SCEC SMDB was converted to a web based system that allowed users to access the data from a variety of different approaches such as clickable maps, event name, station name or various search parameters. The SCEC database SMDB exists but has been reorganized and is affiliated with the COSMOS Virtual Data Center (Consortium of Organizations of Strong Motion Observation Systems) which represents the primary organizations in the US who collect strong motion data. The database now includes all of the US strong motion data, data from Japan's Knet and KIK-net, Europe, New Zealand, as well as other international agencies. What started as a searchable database for SCEC scientists has evolved into the strong motion data center serving an international community of scientists and engineers.

E. Piñon Flat Observatory

The Southern California Earthquake Center has provided partial, but crucial, support to Pinon Flat Observatory (PFO) over the entire period of SCEC1. PFO includes a uniquely powerful collection of high-quality strain and tilt measurement systems, which have provided continuous monitoring of deformation in southern California for over two decades. The SCEC funding has allowed these measurements to continue into the era of continuous GPS measurements, which these instruments complement: together these systems give a temporally and spatially detailed picture of deformations associated with the seismic cycle in southern California.

Over the lifetime of SCEC two significant earthquakes have occurred near PFO: Landers in 1992 and Hector Mine in 1999. In each case the PFO data played a major role in short-term assessments of the possible hazard from triggering of the San Andreas fault (negative in both cases). Both earthquakes showed postseismic deformation: for 2 years after Landers, and for several months after Hector Mine. Aside from these perturbations, the measured strainfield has been free of other temporal fluctuations: a result which helped to guide the planning of the SCIGN array, and the analysis of GPS data for the SCEC Crustal Motion Map.

IX. Observations on the Human Dimension

Shared and distributed leadership was one of the keys to the Center's success. Management was shared between a Center Director (the PI and ultimate mediator – had veto power over Board decisions), a Science Director (who worked with the focus group leaders to assemble the science plan), a Board of Directors (the Center's decision-making body made up of one member per core institution – elected the Center and Science Directors), and the focus group leaders (responsible for coordinating research and science planning within their respective focus groups).

Participation in Center management was exclusively by U.S. citizens, although not by choice, while participation in Center science involved large contingents of both citizen and non-citizen researchers. Center management worked hard to engage the relatively few women earthquake scientists (both post-Ph.D. researchers and students). We were particularly successful in this regard – most notably in the research activities, but less so in management.

X. Institutional Impacts

The principal impact of the Center upon the lead institution as well as the core institutions was increased recognition of the earth sciences by university administrators. At USC, this involved additional faculty hires and financial resources.

XI. Shared Experimental Facilities (SEFs) since the last reporting period.

See Section VIII.

XII. Administration and Management

A. *Phasing Out of NSF Support*

Knowing from the start, that funding would be reduced in years 10 and 11, helped smooth the phasing out process of the S&T Center. However, the biggest issue we faced was whether or not the Center could continue under the ongoing S&T Centers program, or through some other mechanism at NSF. The message we received in this regard was muddled and ambiguous. By the end of the 11th year, SCEC was well received by the scientific community, by the NSF Earth Sciences

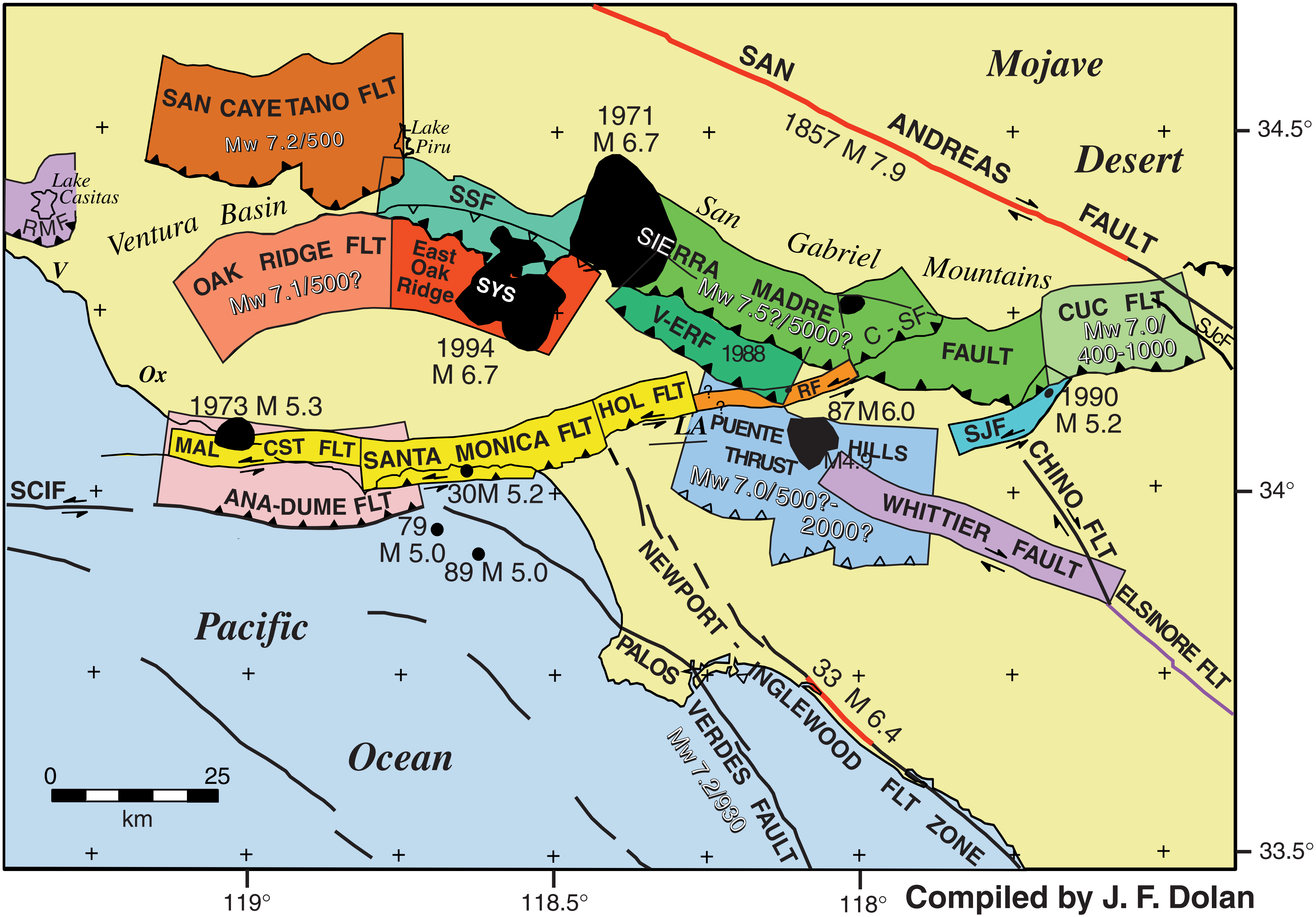
Division (program oversight), and by the USGS (from which the Center received about 25% of its funding). More scientists and institutions wanted to participate in a continuing earthquake center. It seemed to us that there were artificial and arbitrary roadblocks at NSF to continuing the Center with NSF funding, particularly given the excellent reputation that SCEC had established within the earthquake science community. We were particularly concerned as to why S&T Centers were being singled out with prescribed lifetimes while many other large-scale entities continue to be funded year after year by NSF. It seemed to us that whether or not to continue a given center should be based on past performance, scientific merit, and an overall cost/benefit analysis vis-à-vis NSF, the scientific community, and the nation as a whole, rather than on some arbitrary decision.

B. Continuation of the Center

Under what seemed to be rather arbitrary guidelines established by NSF, the Southern California Earthquake Center reorganized as a stand-alone center with expanded scientific participation and a new focus. The reorganized center, referred to as SCEC2, is being funded jointly by the NSF Earth Sciences Division (at a reduced level) and the USGS. SCEC2 has a broadly structured focus on the physics of the earthquake process, how such advanced knowledge can be used to significantly improve earthquake hazard analysis – specifically the prediction of ground motions from future earthquakes, and how to best implement what has already been learned. Moreover, SCEC2 is developing an IT community-modeling environment in which to carry out its basic research, scientific integration, and implementation. Additional support for this activity has come through a major grant from the NSF IT initiative.

Figure 1

Fault map of the greater Los Angeles region. Strike-slip faults are shown as heavy black lines. Colored strips represent surface projections of thrust faults or faults with appreciable dip. Black patches are the surface projections of recent fault ruptures, including those responsible for the 1971 San Fernando and 1994 Northridge earthquakes.



Compiled by J. F. Dolan

Figure 2

Ground motion simulations for two plausible earthquakes on faults in the Los Angeles basin. Faults are shown as dashed lines; freeways are shown as thin white lines, and the coastline as a heavy white line. Bright colors indicate areas of more intense shaking.

Figure courtesy of K. Olsen.

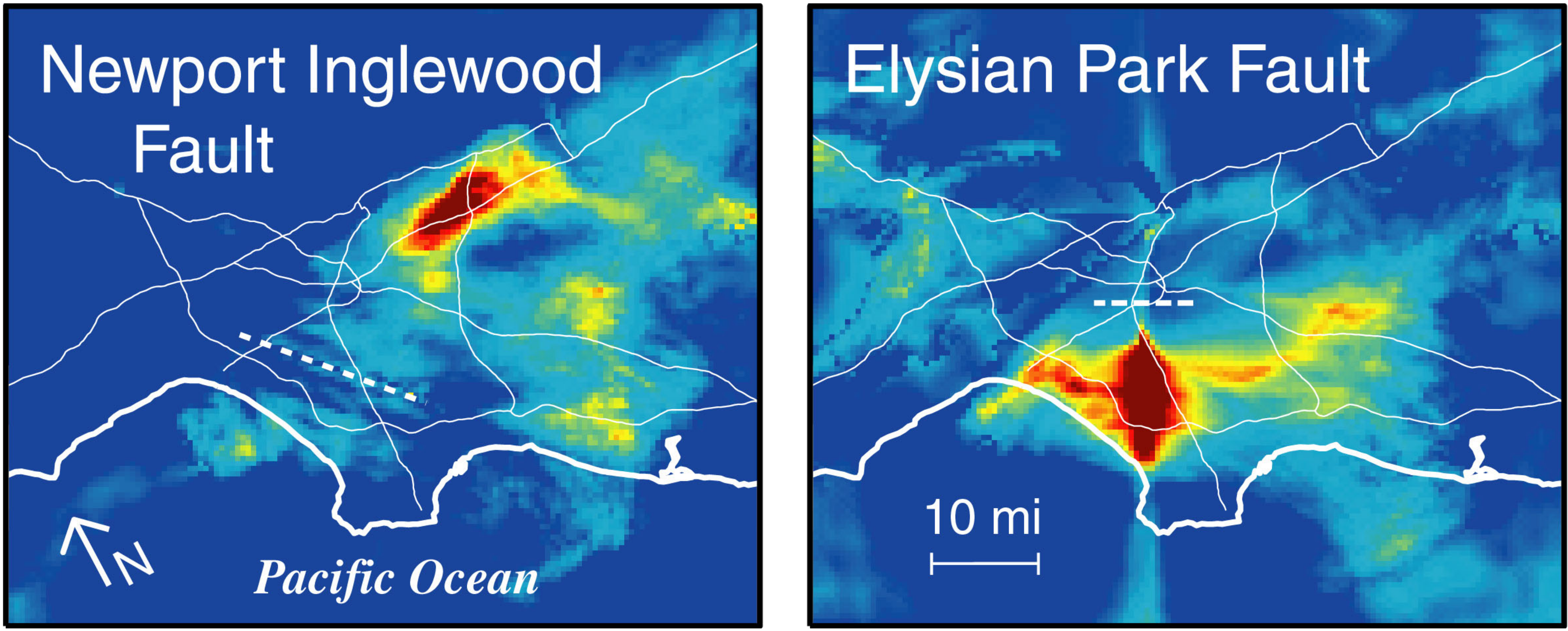
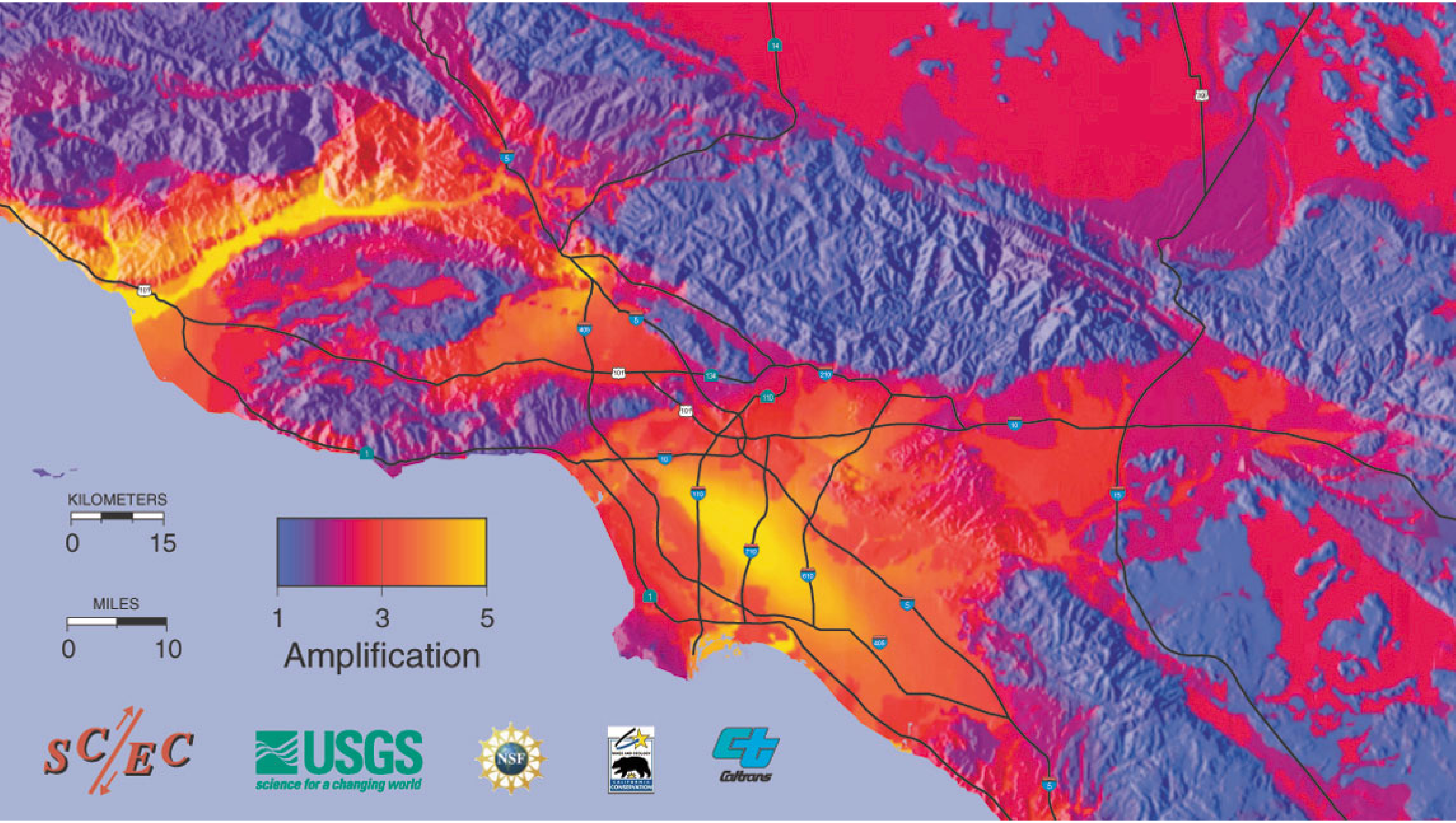

Newport Inglewood Fault
N
Pacific Ocean
Elysian Park Fault
10 mi

Figure 3

Earthquake Ground Motion Amplification in Southern California

The map characterizes the site amplification (1.0-second response spectral acceleration) with two parameters – the shear wave velocity in the upper 30 meters, and the basin depth as defined by the3 2.5 km/sec shear wave velocity iso-surface.

Figure courtesy of E. Field.



KILOMETERS
0 15
MILES
0 10
1 3 5
Amplification
SCEC
USGS
science for a changing world
NSF
Caltrans

Figure 4

Block diagram of the crust beneath a portion of southern California based on a combination of data from the Los Angeles Region Seismic Experiments, regional seismicity, and industry-donated seismic reflection profiles.

Figure courtesy of G. Fuis.

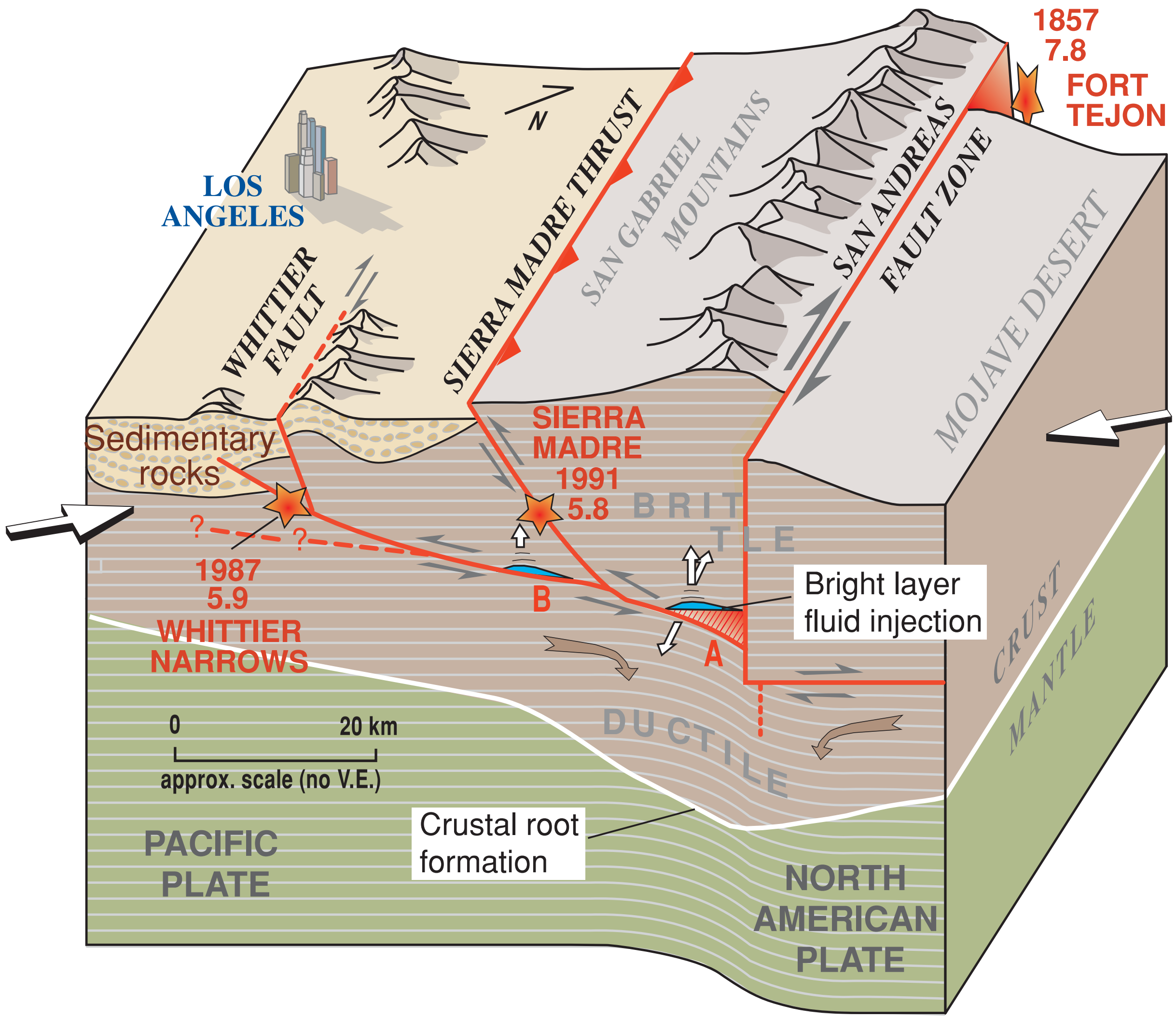
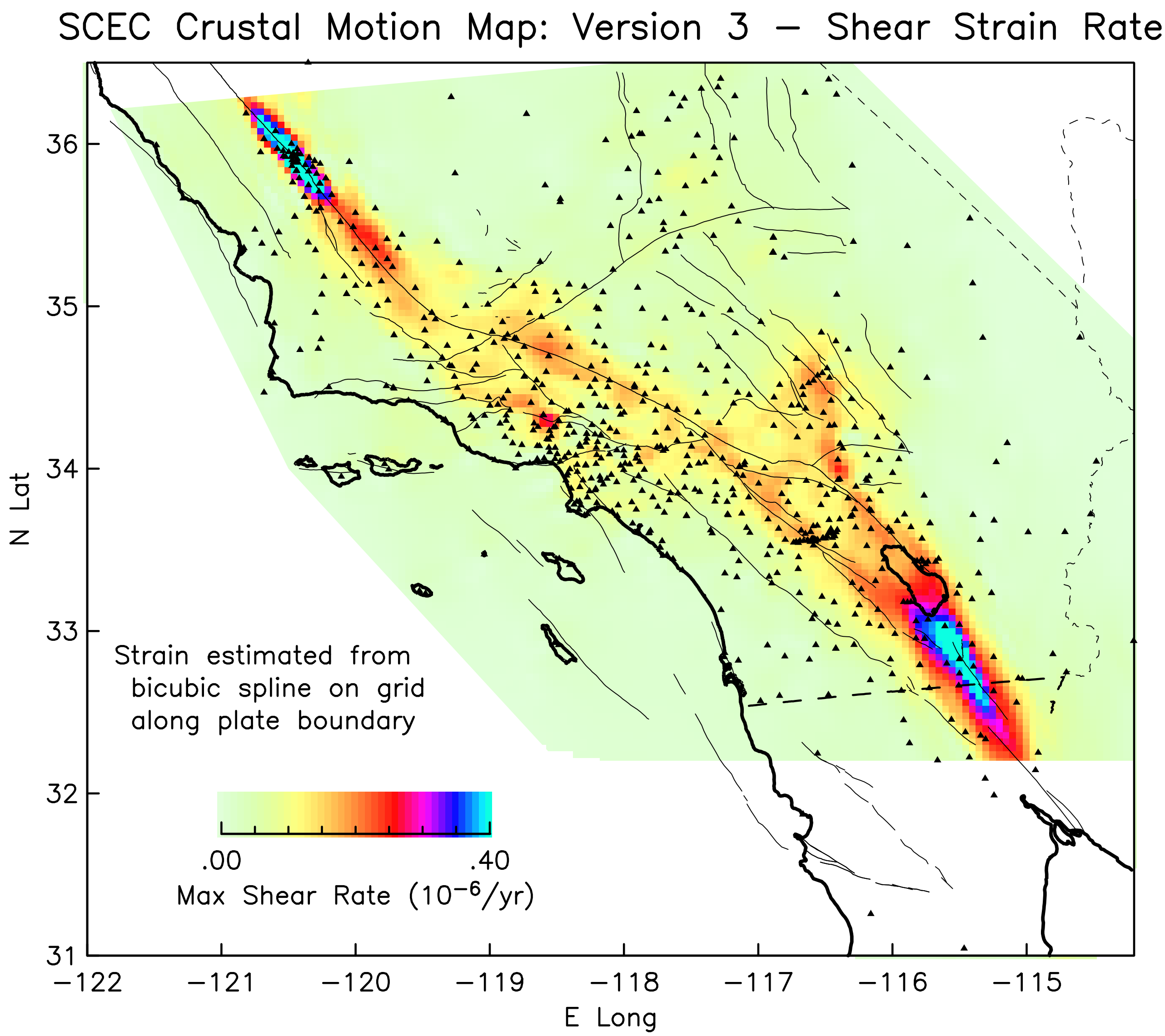

1857
7.8
FORT
TEJON
LOS
ANGELES
N
WHITTIER
FAULT
SIERRA MADRE THRUST
SAN GABRIEL
MOUNTAINS
SAN ANDREAS
FAULT ZONE
MOJAVE DESERT
Sedimentary
rocks
SIERRA
MADRE
1991
5.8
BRITTLE
?
?
1987
5.9
WHITTIER
NARROWS
B
A
Bright layer
fluid injection
DUCTILE
0
20 km
approx. scale (no V.E.)
CRUST
MANTLE
PACIFIC
PLATE
Crustal root
formation
NORTH
AMERICAN
PLATE

Figure 5

Shear strain map for southern California calculated from crustal motions measured by the Southern California Integrated GPS Network (SCIGN) of permanent stations and stations occupied during periodic field campaigns. The distribution of GPS monuments is shown by the small triangles.

Figure courtesy of SCIGN.



SCEC Crustal Motion Map: Version 3 – Shear Strain Rate
36
35
34
33
32
31
N Lat
Strain estimated from
bicubic spline on grid
along plate boundary
.00
.40
Max Shear Rate (10^{-6}/yr)
−122
−121
−120
−119
−118
−117
−116
−115
E Long

Annual Project Summary

Selected highlights of SCEC's integrative, focus group, and outreach activities for the past year are summarized in the following sections.

I. Executive Summary

The 11th and final year of the Southern California Earthquake Center (SCEC) as an NSF Science and Technology Center was spent reaching some prescribed milestones and bringing projects to a logical conclusion under STC funding. Also, inasmuch as the Center is continuing as a stand-alone center with a similar mission but with revised pathways, some new research thrusts were initiated during the year, that built on research done under the original STC.

The Center's third integrative report (Phase III): "Accounting for Site Effects in Probabilistic Seismic Hazard Analyses of Southern California", prepared by SCEC's Master Model (Integrative) Focus Group, was finally published as 14 articles in a special issue of the Bulletin of the Seismological Society of America (vol. 90, no. 6, Part B). The report explores the extent to which probabilistic seismic hazard analysis can be improved by accounting for site effects. The major finding was the fact that amplification at a particular site depended on a combination of the shear wave velocity in the upper 30 meters of crust and the depth of Tertiary sediments in the basin beneath the site. A map of the greater Los Angeles metropolitan area was generated based on these findings and is available as a poster on the SCEC web site (www.scec.org).

During the past year, we also initiated our fourth integrative report (Phase IV): "Regional Earthquake Likelihood Models (RELM)". RELM will extend and update much of the content in our Phase II study by:

- Developing a variety of viable, geophysically-based earthquake-forecast models for southern California (i.e., where and how often all damaging earthquakes are likely to occur);
- Testing these models for consistency with existing geophysical data (e.g., historical seismicity); and
- Examining and comparing the implications of each model with respect to their effect on probabilistic seismic hazard analysis (PSHA).

This will:

- Help define existing uncertainties in seismic hazard analysis;
- Identify the research topics needed to reduce these uncertainties; and
- Identify which models are exportable to other seismogenic regions.

A group from SCEC's Crustal Deformation Focus Group working together with personnel from the USGS and JPL completed the Southern California Integrated GPS Network (SCIGN) that was begun in 1996. The 250th and final SCIGN station was installed on July 2, 2001. On July 6, 2001, the SCIGN team officially dedicated the array with a ceremony held at the Glendale Civic Auditorium. The location of the ceremony was chosen for its proximity to another cutting-edge piece of geodetic instrumentation connected with SCIGN – a new long-baseline strainmeter in the final stages of completion alongside the Glendale Freeway. The 0.5 km long strainmeter is embedded within the SCIGN array, and, together with an existing long baseline strainmeter at Piñon Flat southwest of Palm Springs (also partially funded by SCEC) will be used to independently check signals recorded by the GPS receivers. The sensitivity of these strainmeters is such that if the Los Angeles basin were to be squeezed over its entire breadth by the thickness of a human hair, the effect could be detected. Finally, it is important to note that SCIGN has now become of great interest to, and is partially supported by the California professional surveying community. A new center – the California Spatial Reference Center – has been established at Scripps Institution of Oceanography to address the various agencies needs.

The SCEC Focus Group on Earthquake Geology prepared a summary and evaluation of earthquake fault sources in the Los Angeles Basin and nearby urbanized areas. This report brought our understanding of the regions active faults up to date, based on a decade of work by SCEC researchers and colleagues at the USGS. The objective of the evaluation was to determine the location of active faults and their slip rates and earthquake recurrence intervals – critical input to hazard models. The synopsis includes, in addition to the location and dip of those faults reaching the surface, our current knowledge of blind faults that are expressed at the surface only by folding or elevated topography.

The SCEC Focus Group on Ground Motions continued their very important work on 3-D modeling of ground motions in the greater Los Angeles metropolitan area from scenario earthquakes. Ground motion simulations represent the most direct connection between earth scientists in SCEC and both practicing and research engineers (e.g., those in the NSF Earthquake Engineering Research Centers).

These connections represent a major thrust by the SCEC Ground Motion Focus Group in conjunction with our Knowledge Transfer activity.

A principal activity of the SCEC Seismology Focus Group has been developing 3-D seismic velocity models of southern California designed to serve as reference models for a variety of multidisciplinary research activities, including ground motion simulations, subsurface geologic structure, and seismicity patterns. The most recent version (Version 3.0) was completed the past year, and consists of rule-based representations of the major southern California basins, embedded in a 3-D crust over a variable depth Moho. The seismic velocity model exists as a standard Fortran code and associated files available on the SCEC data center server. In addition to SCEC scientists, many non-SCEC researchers and organizations access the model. Users download the code and generate model values on their local computers.

A second important activity of the Seismology Focus Group involved bringing the study of fault zone trapped waves in the Eastern Mojave Shear Zone (locus of the 1992 Landers and 1999 Hector Mine earthquakes) to a logical conclusion with a study of the complex multiple rupture pattern of the 1999 Hector Mine earthquake. These studies have provided some of the best evidence of both fault zone structure and healing of the zone in the aftermath of the mainshock. This work has particularly important application in rupture modeling as input to ground motion simulations. Moreover, the spatial and temporal characteristics of healing may help us understand the extent of damage to the rock mass in the fault zone, and to estimate dynamic stresses and nonlinear energy dissipation during rupture.

Finally, the Earthquake Physics Focus Group has been exploring rupture through fault branches and activation of secondary faulting. This recent line of investigation supercedes the Center's work on single segment ruptures, and is motivated by the fact that major earthquakes seldom rupture along single planar faults. Instead there exist geometric complexities including fault bends, branches and stopovers that affect the rupture process, including nucleation and arrest.

II. Focus Group Summaries

A. Master Model (Integrative) Focus Group

Phase III Report and Amplification Map The SCEC Phase III Working Group completed their work on determining the extent to which probabilistic seismic hazard analysis can be improved by accounting for site effects with the publication of a series of reports in a December 2000 special issue of the Bulletin of the Seismological Society of America, and publication of an earthquake ground motion amplification map for southern California later in 2001. Southern California was used as the natural laboratory for this study.

The Phase III Report defined the site effect, vis-à-vis probabilistic seismic hazard analysis, as the response, relative to an attenuation relationship, averaged over all damaging earthquakes in the region. Efforts were made to identify any attributes that predispose a site to greater or lower levels of shaking. The most detailed maps of Quaternary geology were not found to be helpful in this regard – either they are overly detailed in terms of distinguishing different amplification factors, or current southern California strong-motion observations are inadequate to reveal their superiority. However, a map based on the average shear-wave velocity in the upper 30 meters was found to delineate significantly different amplification factors. A correlation of amplification with basin depth also was found to be significant, implying up to a factor of two difference between the shallowest and deepest parts of the Los Angeles basin. Questions remain as to whether basin depth is a proxy for some other site attribute.

In spite of these important site effects, the standard deviation of an attenuation relationship (the prediction error) will not be significantly reduced by making such corrections. That is, given the influence of basin-edge-induced waves, subsurface focusing, and general scattering, any model that attempts to predict ground motion with only a few parameters will have a substantial intrinsic variability.

Although all attenuation relationships evaluated in the Phase III studies are viable, the study found that those that incorporate both the detailed shear-wave classification in the upper 30 meters and the basin depth effect at all sites are most promising. Also, because the relationships were tested against the existing southern California strong motion database, it must be assumed that the database is representative of average long-term behavior.

In summary, the large variability in ground motion exceedance levels predicted by different attenuation relationships investigated in Phase III, highlights the importance of understanding ground motion under conditions that dominate the hazard (e.g., M ≥ 6.75 earthquakes at distances less than ~20 km). Moreover, the influence of sediment non-linearity at high ground motion levels must ultimately be considered. Because southern California data are presently inadequate to resolve these issues, we must either wait for more observations or include data from other regions. However, important intrinsic uncertainties will almost certainly always remain. Perhaps the most important conclusion is that our best hope for dramatically reducing the uncertainty of ground motion prediction will be to model the ground motions explicitly from first principles of physics, i.e., waveform modeling. The accuracy and upper limits in wave frequency of waveform modeling will inevitably increase in the future with more refined geologic structural models and advances in high-performance computing.

Following publication of the results of Phase III, SCEC together with the USGS and the California Division of Mines and Geology produced a full-color map and poster of the earthquake ground-motion amplification in southern California. The two most important factors influencing the level of earthquake ground motion at a site are the magnitude and distance of the earthquake. This new map shows the influence of a third important factor, the site effect, by which local geologic and structural conditions can amplify or de-amplify the ground motion. Specifically, the map combines the shear-wave velocity in the upper 30 meters with the basin depth as determined by the 2.5 km/sec shear-wave velocity iso-surface in the SCEC 3D velocity model for southern California, to generate amplifications based on the best-fitting attenuation relationship, and for 1.0-second response spectral acceleration. Posters are available from the Southern California Earthquake Center (www.scec.org).

RELM Following the series of collaborative studies and reports referred to as "SCEC Phases I, II, and III", we are proceeding with Phase IV (RELM – Regional Earthquake Likelihood Models), an update of Phase II (source characterization). The SCEC RELM Working Group is led by Ned Field of the USGS (see also www.relm.org).

In contrast to previous efforts, the goal of RELM is not to develop a single “consensus source model”, but rather to develop a variety of viable models based on various geophysical constraints (e.g., seismicity, geology, geodesy, stress transfer, and/or foreshock/aftershock statistics). There are several reasons for this approach, one of which is to determine the uncertainty of hazard levels given alternative models. Another is to evaluate which models are exportable to other regions where the options are fewer.

The effort includes the compilation of an earthquake catalog, a fault-parameter database, and geodetic observations (all to be web accessible). In addition to the RELM Working Group, some of the data gathering efforts are being broadened and subsumed by other SCEC focus groups.

Part of the goal of RELM is to evaluate the hazard implications of each earthquake-forecast model. This was done in the past by making hard-wired modifications to existing Fortran PSHA codes. One problem with this approach is that the customized code is useless for doing anything else. A second problem is that some of the models under development in RELM (e.g., those based on short-term foreshock/aftershock statistics) do not fit within the framework of existing PSHA codes, so a major rewrite would be required for their implementation. In addition, no existing PSHA code has all the following desired attributes:

- open source
- well documented
- formally reviewed
- object oriented (ideal for PSHA)
- easily parallelizable
- network savvy, secure, and robust with errors
- web-based applications with a graphical user interface

Therefore, as part of the RELM effort, we have begun the development of new, Java-based PSHA code that will enable all of the above.

The most critical and challenging part of developing object-oriented code is designing the overall framework (defining all object classes and their relationships). Only when this design phase is done, and all associated documentation developed, does the actual programming begin. With SCEC funding we have established the overall framework for the PSHA code (preprint of *SRL* article available upon request), and have begun implementing this framework in Java. Documentation of the more than 60 Java classes is available at www.scec.org/psha/docs.

In addition to being capable of implementing all RELM models currently under development, the code has also been designed to implement all viable intensity-measure relationships (attenuation relationships) including those based on directivity and basin effects. Perhaps most importantly, however, is that the code will capable of handling several anticipated future developments without rewriting any code. Examples include the implementation of new and different “Intensity Measures” (functionals of ground motion found to correlate with damage) and vector-valued PSHA, both of which are being developed by the Pacific Earthquake Engineering Center (PEER) and will be a future topic of SCEC-PEER interaction. In addition, the code has been designed so that ground-motion estimates can be based on suites of 3D synthetic seismograms rather than on empirical “attenuation” relationships (i.e., when mature models from the SCEC Ground Motions Focus Group will be available). In summary, much effort has gone into designing an overall seismic-hazard analysis framework that will accommodate ongoing developments in virtually all components of SCEC and other organizations such as PEER.

The following additional information can be obtained at the RELM web site:

- Mission and Goals
- Background & Overview
- Models Under Development
- Supporting Efforts and Databases
- Participants and Email Groups
- SCEC IT Collaboration
- Tutorial Materials
- Schedule and Workshop Reports

B. Crustal Deformation Focus Group

SCIGN The Southern California Integrated GPS Network (SCIGN), under construction since 1995, has now been completed with 254 continuously operating GPS receivers now in place throughout southern California and northern Baja California. SCIGN stations are weighted toward the greater Los Angeles basin where the network is focused on identifying structures, including blind faults that may be responding to tectonic convergence across the region. SCIGN includes three processing centers – at Scripps, JPL, and the USGS – with funding from NSF, NASA, and the USGS. The Scripps Orbit and Permanent Array Center (SOPAC) located at the Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics operates the SCIGN archive, maintains 20% of the network (the remainder maintained by JPL and USGS), and disseminates data and data products both automatically (by anonymous ftp) and interactively (through Web pages). In 2001 1.1M SCIGN data files were copied from SOPAC. Current estimates from JPL and Scripps indicate that the agreement in horizontal motions between the two processing centers is 1.68 ± 2.50 mm/yr north and 1.20 ± 2.28 mm/yr west. In addition to the Los Angeles basin, SCIGN continues its study of the Eastern Mojave Shear Zone, site of the Landers and Hector Mine earthquakes – with a focus on post-earthquake crustal deformation.

Also close to completion and part of SCIGN, is the new 600-meter long baseline laser strainmeter installation along the Glendale Freeway between the 134 and 210 freeways. SCEC is grateful to the California Department of Transportation (Caltrans) for making this excellent site available. The strainmeter is located within the greater Los Angeles basin GPS network in order to provide an independent check on any short-term strain transients that may be detected by one or more GPS receivers. It is anchored at one end in weathered granitic rock, and at the other end in decomposed granite, and oriented roughly in the direction of maximum regional convergence. We anticipate that the instrument will be operational by mid-year 2002.

In order to acknowledge the completion of SCIGN, SCEC held an unveiling event on July 6, 2002. The event was designed to both commemorate the work of the SCIGN team in creating the array and introduce and explain the importance of the project to the public.

Crustal Motion Model SCEC and the Crustal Deformation Focus Group have supported the archiving of survey-mode GPS data in southern California collected by a variety of different groups, in addition to those generated by SCIGN. (Figure 1 from Agnew report) These observations are complementary to SCIGN's continuous observations. While they do not provide equivalent time resolution, they do cover a broader spatial area in much greater detail, and also a longer span of time – in particular, covering the times of the Landers and Northridge earthquakes that occurred before a large number of SCIGN stations had been installed. As such, these data form an important input to the SCEC Crustal Motion Model (CMM) since they not only allow early versions of the model to be developed, but also cover many regions of southern California where few SCIGN measurements are being made, as well as time intervals before the deployment of SCIGN. All survey-mode GPS data have been archived at the SCEC Data Center at Caltech, which makes them freely available.

During the past year, work has progressed on the most recent update of the model (CMM Version 3.0), due to be released later this year (2002). It consists of 787 station velocities in southern California and vicinity with horizontal uncertainties less than 4 mm/yr. Along with secular velocities, the new model also contains coseismic displacements for the 1992 Joshua Tree, 1992 Landers/Big Bear, 1994

Northridge, and 1999 Hector Mine earthquakes. Velocity results show 49mm/yr deformation across the plate boundary in southern California, which is consistent with the NUVEL-1A model prediction. Regional deformation, however, is complex in both space and time.

Although included in CMM, vertical rates have not been considered reliable or used extensively for modeling interseismic and post-seismic deformation. Analysis during the past year suggests that there are now more than 200 stations, both continuous and non-continuous, for which we can obtain vertical rates with uncertainties at the level of 1-2 mm/yr. The intrinsic problem in getting accurate vertical measurements with GPS is that while a GPS antenna can acquire measurements symmetrically in the horizontal plane (except for a 'hole' around the poles due to the geometry of the satellite constellation), it can see only above the horizon, rendering estimates of vertical position highly correlated with three effects on the signal that are difficult to model: atmospheric delay, scattering by surfaces on and near the antenna, and variations in the effective phase-center of the antenna. Short observation sessions, wet weather, a poor choice of antenna mount, and mixing of antennas within a network can conspire to contribute many centimeters of error to the height estimate. The estimates are also confounded by all-too-frequent human errors in measuring or recording the height of the antenna above the reference monument. All of these problems can and have been avoided, however, for a substantial number of GPS stations in southern California. Vertical rates are important for constraining models of both co-seismic and secular motion.

The collaborative nature of the survey-mode data collection, the addition of the SCIGN data as they came on line, and indeed of the entire CMM effort, was only possible because of the support and coordination provided by the Center. In particular, the Center provided:

- Ongoing funding in the form of infrastructure rather than tied to particular PI's;
- A central location where the data could be archived and made available without the Crustal Deformation Focus Group having to fund a separate hardware and software database; and
- A style of encouraging collaborative efforts.

C. Earthquake Geology Focus Group

Active Faults in the Los Angeles Metropolitan Region An evaluation of earthquake fault sources in the Los Angeles Basin and nearby urbanized areas based on fault geology has been prepared by the SCEC Working Group on Earthquake Geology (J. Dolan, E. Gath, L. Grant, M. Legg, S. Lindvall, K. Mueller, M. Oskin, D. Ponti, C. Rubin, T. Rockwell, J. Shaw, J. Treiman, C. Walls, and R. Yeats). Yeats acted as compiler.

The objective of the evaluation was to determine the location of active faults and their slip rates and earthquake recurrence intervals. This includes the location and dip of those faults reaching the surface and blind faults that are expressed at the surface by folding or elevated topography.

Slip rate determinations are based on several timescales. The tectonic regime of the Miocene was generally extensional, and the north-south contractional regime came into being in the early Pliocene. The longest timescale for slip-rate estimates, then, is the time of imposition of the north-south contractional regime, the past 5 x 10^6 years. Another timescale is the early and middle Quaternary (~ 2 x 10^6 years), the time of deposition of the upper Pico member of the Fernando Formation plus the shallow-marine to nonmarine San Pedro Formation. Information for the first two timescales is derived from the subsurface using oil-well and water-well logs, multichannel seismic profiles, and surface geology. A third timescale is the late Quaternary (10^2-10^5 years), information for which is obtained through trench excavations, boreholes, and high-resolution seismic profiles and ground-penetrating radar augmented by the 232-year-long record of historical seismicity in the Los Angeles area. The shortest timescale (10 yrs) is that afforded by repeated GPS observations.

The late Quaternary rate is the most representative long-term rate in forecasting future behavior because it provides a geologically- and statistically-significant averaging time but is unlikely to be contaminated by Pliocene and early Pleistocene geologic processes no longer active today. The late Quaternary rate may be different from the rate based on GPS observations. For example, the GPS rate across the Eastern California Shear Zone is considerably higher than the late Quaternary geologic estimates. In California, similar differences between GPS and geology may occur on the Garlock fault. In this instances, the GPS rate may not be steady state but may represent a short-term strain transient.

This report (available from the Southern California Earthquake Center) summarizes the evidence for slip rates across faults of the Los Angeles metropolitan region and calculates the north-south component of shortening to compare with the convergence rates of about 4.4 mm/yr between downtown Los Angeles and the San Gabriel Mountains based on GPS data.

D. Seismology Focus Group

Last year's principal accomplishments within the Seismology Focus Group fall into three areas:

- Completion of Version 3.0 of the Seismic Velocity Model (SVM) for southern California, and
- Final results from the fault zone trapped wave field studies along the Landers and Hector Mine earthquake ruptures.

Version 3.0 of SVM The Seismic Velocity Model serves as a reference model for other research activities. The most recent model (Version 3.0), updated last year, consists of detailed, rule-based representations of the major southern California basins (Los Angeles basin, Ventura basin, San Gabriel Valley, San Fernando Valley, Chino basin, San Bernardino Valley, and the Salton Trough), embedded in a 3D crust over a variable depth Moho. Shallow basin sediment velocities are constrained by geotechnical data. Outside of the basins, the model's crust is based on regional tomographic results. The model Moho is represented by a surface with depths determined by from receiver functions. The model's upper mantle is based on teleseismic tomographic results. The model is implemented in a computer code that generates any specified 3D mesh of seismic velocity and density values. This parameterization is convenient to store, transfer, and update as new information and verification results become available.

The seismic velocity models have become important focal points within SCEC for diverse data collection, analysis, and interpretation efforts, and have formed the standard for benchmarking different wavefield simulation techniques and comparative modeling of specific ground motion data sets (such as records of the 1994 Northridge earthquake). The recognition of the usefulness of a standard reference seismic velocity model helped to foster the "community model" rubric that has become an important element within SCEC.

The seismic velocity model exists as a standard Fortran code and associated files available at the SCEC Data Center. Many non-SCEC researchers and organizations use the model. Users download the code and generate model values on their local computers. The popularity of the model can be measured by the number of model downloads.

Field Studies of Fault Zone Trapped Waves The Center supported a decade-long field program to investigate the structure of active fault zones using trapped waves. Faults studied included the San Andreas fault at Parkfield, the San Jacinto fault near Anza, and the rupture zones of the 1992 *M*7.3 Landers and 1999 *M*7.1 Hector Mine earthquakes. The most important results were from the earthquake rupture zones.

Immediately after the Landers and Hector Mine earthquakes, linear seismic arrays were deployed across and along the rupture zones to record fault-zone trapped waves generated by aftershocks and near-surface explosions within the rupture zone. Observations coupled with 3-D finite difference simulations of 2-7 Hz trapped waves were used to characterize the internal structure and physical nature of the rupture zones to seismogenic depths. The Landers rupture zone was discovered to be characterized by a low velocity and low *Q* wave-guide, 250 m wide at the surface and tapering to 100-150 m at 10 km. Similar results were found for Hector Mine, but with a somewhat narrower width. The results were interpreted as inelastic deformation around a propagating crack tip during dynamic rupture in earthquakes, with the fault zone widths delineated by the trapped waves scaling to rupture length as predicted by dynamic rupture models.

Of greatest interest was the fact that repeated surveys in ensuing years along the Landers and Hector Mine ruptures using explosions revealed what is believed to be the first definitive evidence of post-earthquake fault healing. At Landers, S-wave velocities in the fault zone increased by ~1.2% between 1994 and 1996, and by ~0.7% between 1996 and 1998, suggesting the rupture zone had strengthened, ostensibly due to the closure of cracks that opened during the 1992 earthquake. The observed fault strength recovery was found to be consistent with a decrease of ~0.03 in apparent crack density within the fault zone. At Hector Mine S-wave velocities within the rupture zone were found to have increased by 0.65-1.0% between 2000 and 2001 with a greater change within sedimentary sites than in hard rock sites. Also, the healing rate varied from one fault segment to another, probably due to a combination of material heterogeneity/non-linearity and stress changes along the rupture zone.

E. Ground Motion Focus Group

3-D Wave Propagation Codes During the final years of SCEC, a principal activity of the Ground Motion focus group has been to develop and verify waveform simulation methodologies to accurately model ground motions in 3-D heterogeneous media. This comprehensive project has fostered extensive collaboration among SCEC researchers, and between SCEC and PEER. For example, the expertise of geologist (who define the geologic structures and faults), seismologists (who develop and apply the ground motion simulation methodologies, and engineers (who will use the ground motion estimates for hazard analysis) have been productively combined and continued during the past year.

An important endeavor during the past year has been development of the methodology for 3-D wave propagation in realistic anelastic structures. The challenge in computing anelastic energy losses in finite difference wave propagation codes is that the quality factor, Q, for rock and soil is roughly frequency-independent. SCEC researchers have developed improved methods that closely model the frequency-independence of Q while being efficient enough for use in 3-D wave simulations.

The main impediment to realistic treatment of anelastic attenuation in 3-D is the very large computational storage requirement imposed by the additional variables. In one study, a previously proposed alternative to the conventional memory-variable formulation – i.e., the memory-efficient method of coarse-grain memory variables that had been demonstrated to be effective in acoustic problems – was generalized to 3-D anelasticity, and implemented using a fourth-order, staggered-grid finite difference scheme. The anelastic coarse-grain method applied to plane-wave propagation successfully simulated frequency-independent Q_p and Q_s. Apparent Q's are constant to within 4% tolerance over approximately two decades in frequency, and biased less than 4% from specified target values. This performance is comparable to that achieved previously for acoustic wave propagation, and could be further improved by optimizing the memory-variable relaxation times and weights.

A second study, building on the first one, developed a theoretical analysis of the stability and accuracy of the coarse-grain memory variable technique used for 3-D viscoelastic wave field simulations. This study showed that the behavior of the coarse-grain system is best described by effective parameters (M_E and Q_E) that are derived from the harmonic average of the moduli over the volume of the coarse-grain cell. The use of these effective parameters is essential for analyzing the performance and accuracy of the coarse-grain system, particularly for low values of Q. In addition, this second study derived an improved formulation of the original coarse-grain methodology called the element specific modulus (ESM) formulation. In the ESM formulation, each element of the coarse-grain cell uses a different unrelaxed modulus. It was found that the accuracy of the coarse-grain system for Q values lower than about 20 was significantly increased by using the ESM formulation, with no additional cost for implementation.

Site Response and Non-linearity Previously, SCEC researchers developed a method to estimate S-wave site amplification relative to a regional layered velocity model. In this method, the site response function is defined as a ratio of ground response of empirical Green's function to synthetic Green's function. There are several advantages of this method. Source-station geometry and the focal mechanism are incorporated. Since the empirical site response is referenced to a regional layered crustal model, for which the theoretical site response is exactly known, the result can be applied directly to the site-specific synthetic ground motion prediction. Using this method, site amplifications can be estimated even though there is no rock reference station available. Moreover, the empirical site response can be converted to any other reference standards such as a selected rock site or average of several selected sites when that is needed. Under this approach, site response at different sites over a great distance range can be compared as long as they share the same regional structure.

The foregoing approach was used to estimate both weak and strong motion site response from the Northridge earthquake sequence. By comparing weak and strong motion site response at co-located sites, it was found that for stations with relatively smaller ground motions, the two site response functions agree within the uncertainty. However, significant differences between the two site response functions were found at stations that recorded peak ground acceleration of the mainshock above 0.3g, peak velocity above 20 cm/sec, or peak strain above 0.06%. These differences increased as the peak ground motions increased. This result is a direct demonstration (from the ground motion observations) of the relationship between nonlinear site response and peak ground motion parameters. It also indicates that the nonlinearity is not only present in sediment sites but also on soft rock sites. The trends in the data can be used as a baseline for constraining future synthetic ground motion modeling.

F. Earthquake Physics Focus Group

The Earthquake Physics Working Group is developing theoretical foundations and physical models to support advances in earthquake hazard assessment. Research is directed toward: 1) Improved models of time-dependent rupture and slip in individual earthquakes that aid estimates of earthquake potential, constrain ground motion simulation methodologies, and reveal fundamental source processes by connecting kinematic observations (from seismology, geodesy, and geology) with fault-zone physics, and 2) Improved models for the space-time evolution of earthquake sequences, fault system structure, and regional stress fields that are aimed at improving an understanding of the nature of short- and long-range interactions and correlations among seismic events, and have the long-term goal of improving time-dependent probabilistic estimates of earthquake potential.

Results from numerical simulations of rupture in the presence of heterogeneities suggest that dynamic rupture may be controlled by heterogeneities in the distributions of either initial stress or friction. Either type of heterogeneity can yield simulations that reproduce strong motion recordings of, for example, the 1992 Landers earthquake, suggesting that rupture propagation is principally controlled by the ratio of available strain energy to fracture energy. A theoretical demonstration and numerical examples showed that Coulomb sliding along a material interface is well posed provided small viscoelastic losses are present in the elastic medium. This regularization mechanism provides an alternative to modifying the Coulomb friction law to give it memory of past changes in normal stress, and leads to convergent numerical simulations. Also, regularized rupture simulations at a material interface were shown to evolve a self-sharpening, unidirectional pulse mode of rupture.

Numerical modeling methodology was further advanced through development of a 3D, hybrid method for simulating rupture on faults with complex geometry. The dynamic rupture propagation is computed using the boundary integral equation (BIE) method. The computation of radiated waves outside the fault is carried out by an efficient fourth-order staggered-grid finite-difference (FD) method. The hybrid method enables dynamic modeling of rupture propagation on curved or multi-segmented faults in laterally and vertically heterogeneous earth models with an accurate free surface.

Earthquake nucleation and early rupture propagation were also the subjects of numerical studies. These simulations were shown to produce fluctuations in moment rate at nucleation, due to stress inhomogeneities and intermittent rupture arrest in the creeping zone. The simulated moment rate fluctuations are similar to those associated with observed nucleation phases, being characterized by slow, irregular moment release followed by speedup. Notably, the current model shows no differences in nucleation phase between large and small events, and predicts clustering at the transition between creeping and locked zones. The later behavior bears similarity to transitional behavior observed on the San Andreas and Calaveras Faults in central California.

New ground was broken in the understanding of rupture branching and segmentation. Notable was the emergence of branching models with self-selection of rupture path. Theoretical work showed that branch selection depends upon the ratio of horizontal principal stresses and rupture velocity. Preliminary numerical simulations in 2D corroborate the theory. A segmented rupture simulation, in 3D, of the 1999 Izmit, Turkey earthquake was compared with the documented behavior of that event. The segmented model successfully mimicked the stepover rupture pattern of the event and predicted intersonic rupture of the segment east of the epicenter, consistent with inferences from some independent investigations based on the recorded ground motion.

Numerical simulations also were used to relate rupture physics to the excitation of near-fault ground motion. Strong, near-fault directivity pulses develop in these simulations, with peak velocity ratios between forward and backward directivity directions exceeding 4. Numerical simulations have been shown to closely reproduce the near-fault motions observed in scale-model experiments. Near-fault directivity effects were diminished, but not eliminated, by the presence of highly heterogeneous pre-stress and strength conditions.

III. Communication, Education, and Outreach Activities

The transfer of SCEC's research results to other communities as an essential component of its mission. The SCEC Communication, Education and Outreach (CEO) program has established itself as a valuable resource for southern California.

SCEC CEO's long-term goals were:

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

SCEC's CEO program pursued four main objectives:

- Build upon student and public interest in the natural environment,
- Utilize the scientific and educational expertise of SCEC in outreach and knowledge transfer,
- Expand access to earthquake information via the Internet and other media, and
- Foster a greater public understanding of earthquake risk.

Following are highlights of SCEC's 2001 CEO program.

A. Education Activities

SCEC Museum Partnerships. SCEC 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 ("ShakeZone") in their region. The mission of the exhibit, which opened January 17, 2002, 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 presents information about science, engineering, safety and mitigation. A shake table, an interactive computer display, and wall displays teach the visitors about the tools and techniques of earth scientists, engineers and emergency services personnel.

2001 Summer Internship Program. To provide hands-on experiences in the earth sciences, provide insights into career opportunities, and interest underrepresented undergraduate students in Earth science-related careers, SCEC has funded 72 students to date (including 39 women and 16 minority students) to work alongside 50 SCEC scientists over the past 7 years. Although the program was not funded last year by SCEC directly due to budget constraints, 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.

Seismic Sleuths Revision. SCEC has revised 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.

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).

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.

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.

USGS/SCEC/IRIS Teacher Education Workshops. On November 17th, 2001, the Southern California Office of the U.S. Geological Survey and SCEC held an earthquake education workshop at Polytechnic School in Pasadena, CA. The workshop explored the science of earthquakes and applied those concepts to a wide range of activities. The Incorporated Research Institutions for Seismology (IRIS), provided curriculum materials, posters, books and many of the supplies for the workshop. The objective of the workshop was to present educators with earth science and earthquake materials and activities that they could take back to their students. This was the first of many planned workshops.

Electronic Encyclopedia of Earthquakes. (www.scec.org/ecube) This collaborative project between SCEC, CUREE and IRIS is synthesizing a large and varied amount of data and information, and providing broad access via the Internet in the context of the Digital Library for Earth System Education (DLESE). The subject matter features earth science as well as principles of 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 framework for the Encyclopedia has been developed and the content collection process is on-going.

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.

B. Public Outreach Activities

SCEC Webservice and SCEC InstaNET News. (http://www.scec.org) SCEC's webservice 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.

EqIP. (www.eqnet.org) 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, 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 EqIP's website which provides a database of descriptions of over 250 organizations with links to their websites. In 2001, SCEC CEO developed an online survey of EqIP members to assess EqIPs success. SCEC’s Director for CEO is now the Chair of this group.

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 continue 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.

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 attended), 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)

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, located on the Carrizo Plain – a 3-4 hour drive north of 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.

C. Knowledge Transfer Activities

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.

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 was titled "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.

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.

Appendix A
Current List of SCEC/STC-Supported Publications

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Appendix B and H2/3
List of MS/PhD/Post-Doctoral Students During Life of SCEC

Institution	Student/Post-Doc	Degree	Year Graduate	Current Position
ASU	Elizabeth Stone	M. S.	2000	Staff Geologist at Ninyo and Moore
ASU	George Hilley	Ph.D	2001	Alexander von Humboldt Scholar at the University of Potsdam
ASU	Jeri Young	Ph.D. candidate	expected 2003	
Caltech	Anupama Venkataraman	Ph.D.	2002	
Caltech	Craig Scrivner	Ph.D.	1999	Central Washington University, Ellensburg, WA
Caltech	Dapeng Zhao	Post-doc		Professor at Ehime University, Japan
Caltech	Dr. Shelley Kenner	Post-doc		Assistant Professor at University of Kentucky
Caltech	Dr. Yuri Fialko	Post-doc		Assistant Professor at University of California, San Diego
Caltech	Emily Brodsky	Ph.D.	2000	Assistant Professor, UCLA
Caltech	J. Douglas Yule	Post-doc	1995–1999	Assistant Professor, Cal State University, Northridge
Caltech	James Dolan	Post-doc	1991–1994	Associate Professor, USC
Caltech	James Spotila	Ph.D.	1999	Assistant Professor, Virginia Polytechnic Institute and State Univ.
Caltech	Jeanne L. Hardebeck	Ph.D.	2000	Post-Doctoral Scholar, UCSD
Caltech	Jing Liu	Ph.D.	in progress	
Caltech	Jishu Deng	Post-doc		New York financial market research for J.P. Morgan
Caltech	Judith Zachariasen	Ph.D.	1998	Whitman College Zone
Caltech	Julie J. Nazareth	Ph.D	2002	
Caltech	Kenneth Hudnut	Post-doc	1988–1992	USGS, Pasadena office
Caltech	Leo Eisner	Ph.D.	June, 2001	Post-Doctoral Fellow
Caltech	Lisa Grant	Ph.D.	1993	Assistant Professor, University of California, Irvine
Caltech	Lupei Zhu	Ph.D.	1997	Assistant Professor, St. Louis University, St. Louis, MO
Caltech	Michael Oskin	Ph.D.	2002	Post-doc at UC Santa Barbara
Caltech	Sally McGill	Ph.D.	1991	Associate Professor, Cal State San Bernardino
Caltech	Tamao Sato	Post-doc		Professor at Hirosaki University, Japan
Caltech	Xi J. Song	Ph.D.	1995	Software Technologies Corporation, Monrovia, CA
Caltech	Yann Klinger	Post-doc	1999–2001	IPG Paris
Caltech	Zhimei Yan	Ph.D.	1996	
Colorado, Boulder	Dr. Jorge S.S. Martins	Post-doc		Assistant Professor, University of Brazil
Colorado, Boulder	Dr. Kristy Tiampo	Post-doc		Post-Doctoral Scholar, University of Colorado
CWU	Ashley Streig	in progress, M.S.		

CWU	Carmen Von Stein	intern - undergrad		
CWU	Chris Madden	M.S.	1996	Unknown
CWU	Christian Walls	intern - undergrad		
Delft Institute of Techr	Paul J. de Jonge (SIO)	Ph.D.	1998	Post-Doctoral Fellow
Harvard	Alain Cochard	Post-doc		Currently Unemployed
Harvard	Alexei N.B Poliakov	Post-doc		Laboratoire de Geophysique et Tectonique, Montpellier II, France.
Harvard	Andreas Plesch	Post-doc		Post-Doctoral Scholar, Harvard
Harvard	Carlos Rivero	M.S.	2000	enrolled in Ph.D. program at Harvard
Harvard	Chris Guzofski			enrolled in Ph.D. program at Harvard
Harvard	Christiane Stidham	Post-doc		Harvard
Harvard	Freddy Corredor	M.S.	2001	enrolled in Ph.D. program at Harvard
Harvard	Gilles Perrin	Post-doc		Faculty, Ecole Polytechnique,, Institut Francais du Petrole, France.
Harvard	Gutuan Zheng	Ph.D.	1995	Engineer, Operations Technology Group, IBM,Somers, NY.
Harvard	Koji Uenishi	Post-doc		Faculty, Department of Civil Engineering, Kobe University, Japan
Harvard	Kunnath Ranjith	Ph.D.	1998	Postdoctoral Fellow, California Institute of Technology.
Harvard	M. Peter Süss	Post-doc		Assistant Professor at Tubingen University, Germany
Harvard	Mark A.J Taylor	Ph.D.	1999	Fixed Income Division, Morgan Stanley Dean Witter, London.
Harvard	Michael L Falk	Post-doc		Faculty, Applied Physics and Materials Science, Univ. of Michigan
Harvard	Nadia Lapusta	Post-doc		Solid Mechanics, Harvard University.
Harvard	Nadia Lapusta	Ph.D.	2000	Postdoctoral Fellow, Harvard University
Harvard	Nobuki Kame	Post-doc		Researcher, Earth and Planetary Sciences, Kyushu University, Japan
Harvard	Philippe H Geubelle	Post-doc		Faculty, Aeronautical and Astronautical Engineering, UIUC
Harvard	Rachel E. Abercrombie	Post-doc		Faculty, Department of Earth Sciences, Boston University
Harvard	Renata Dmowska	Post-doc		Research Associate in Geophysics, Harvard University
Harvard	Yehuda Ben-Zion	Post-doc		Faculty, Earth Sciences, University of Southern California
JPL	Debbie Dauger	Ph.D.	1996	California Institute of Technology
JPL	Margaret Glasscoe	Ph.D.	in progress	University of California, Davis
JPL	Mousumi Roy	post-doc		Assistant Professor, University of New Mexico
LDEO	Dr. Jishu Deng	Ph.D.	1996	New York financial market research for J.P. Morgan
LDEO	Dr. Mark D. Petersen	Ph.D.	1992	Research Scientist at USGS
LDEO	Dr. Steven Jaumé	Ph.D.	1995	Assoc. Prof., University of Charleston (SC)
LDEO	Mr. Wen-Xuan Du	Ph.D. to be complet	2002	
Long Beach St.	Safaa Dergham	MS	2001	Associate 5 Geologist for ENVIRON International Corporation
MIT	Danan Dong	Ph.D.	1993	Research Staff at JPL
MIT	Elizabeth H. Hearn	Post-doc	1999-2002	Assistant Professor at the University of British Columbia.
MIT	Kurt L Feigl	Ph.D.	1991	Research Staff CNRS, Toulouse

MIT	Mark H. Murray	Ph.D.	1991	Research Staff, UC-Berkeley
MIT	Richard A. Bennett	Ph.D.	1995	Research Staff at Harvard-Smithsonian Center for Astrophysics
MIT	Simon C. McClusky	Post-doc	1993-1996	Research Staff at MIT
SDSU	Altangerel Orgil	MS	2001	
SDSU	Charles Holzer	MS	1996	Exxon-Mobil, Houston
SDSU	Charles Houser	MS	1996	
SDSU	Christophe Voisin	Post-doc		SDSU
SDSU	David Oglesby	Post-doc		Assistant Professor, U.C. Riverside
SDSU	Deems Padgett	MS	1994	
SDSU	Diane Murbach	MS	1995	
SDSU	Geoff Ely	MS	1998	U.C. San Diego
SDSU	Hans van de Vrugt	MS	1999	Ninyo and Moore, San Diego
SDSU	Jennifer Lewis	MS	1994	Chevron-Texaco, New Orleans
SDSU	John Helms	MS	1996	
SDSU	Kenji Hirabayashi	MS	1995	
SDSU	Kevin Bryan	MS	1995	
SDSU	Kevin Colson	MS	1996	
SDSU	Kimberly Thorup	MS	1998	GIA, San Diego, CA
SDSU	Lawrence Gurrola	MS	1994	
SDSU	Maria Hertzberg	MS	1996	
SDSU	Monte Murbach	MS	2000	
SDSU	Tim Dawson	MS	2000	Research Staff, USGS
SDSU	Yu Guang	Post-doc		Computer Programmer in Minneapolis, Minnesota
UCLA	Herbert Rendon	Ph.D	1996	Scientist, Venezuelan Geological Survey FUNIVIS
UCLA	Kelly Liu	Ph.D	1997	Assistant Professor, U. Kansas
UCLA	Monica Kohler	Post-doc		UCLA Professional Researcher
UCLA	Shirley Baher	Ph.D	2000	Post Doctoral Fellow, U. Wisconsin
UCSB	Carey Marcinkovich	Defending Spring	2002	
UCSB	David Olgesby	Ph.D., Assistant Pro	1999	Department of Earth Sciences, University of California, Riverside
UCSB	Dr. Kim Olsen	Post-Doc		Institute for Crustal Studies, UCSB, Santa Barbara, CA
UCSB	Dr. Pengcheng Liu	Post-Doc		Institute for Crustal Studies, UCSB, Santa Barbara, CA
UCSB	Ellen Gottschammer	Defending Summer	2002	
UCSB	Grant Lindley	Ph.D, Database spec	2001	ABC Clio, Santa Barbara, CA
UCSB	Jamison Steidl	Ph.D, Research Seis	1995	Institute for Crustal Studies, UCSB, Santa Barbara, CA
UCSB	Larry Gurrola	Ph.D.	1999	
UCSB	Luis Fabian Bonilla	Ph.D, Research Geo	2000	Protection et de Sûreté Nucléaire, Fontenay-aux-Roses, France

UCSB	Molly Trecker	M.S.	1996	
UCSB	Ross Hartleb	M.S.	1997	
UCSB	Ruth Harris	PhD, Geophysicist	1992	U.S. Geological Survey, Menlo Park, CA
UCSB	Sophie Peyrat	Post-Doc	June, 2001	
UCSB	Stefan Nielsen	Post-Doc	1997-2000	Instituto Nazional di Geofisica e Vulcanologia, Italy
UCSC	Sergio Barrientos	Ph.D.	1986	University of Chile, Santiago
UCSC	Luca Valensise	Post-doc	1986-1987	University of Rome
UCSD	Greg Anderson	PhD	2000	USGS in Pasadena
UCSD	Hadley Johnson	PhD	1993	The Prediction Company
UCSD/SIO	Eric Calais	Post-doc	1993-1995	Purdue University, Indiana
UCSD/SIO	Erika Roegis	exchange MS studer	1999	
UCSD/SIO	Jie Zhang	Ph.D	1996	
UCSD/SIO	Joachim Genrich	Post-doc	1992-1997	freelance consultant
UCSD/SIO	Karen Watson	MS	2000	CSRC
UCSD/SIO	Linette Prawirodirdjo	Ph.D.	2000	
UCSD/SIO	Linette Prawirodirdjo	Post-doc	2000-present	
UCSD/SIO	Matthijs van Domselaar	exchange MS studer	1997	Programmer/Analyst at SOPAC (1998-2001)
UCSD/SIO	Paul J. de Jonge	Post-doc	1998-2000	GPS Consultant, in Brazil
UCSD/SIO	Paul Tregoning	Post-doc	1995	Australian National University, Canberra
UCSD/SIO	Rosanne Nikolaidis	PhD candidate	June, 2002	
UCSD/SIO	Shimon Wdowinski	Post-doc	1991-1993	Geophysics and Planetary Sciences, Tel Aviv University, Israel
UCSD/SIO	Simon Williams	Post-doc	1996-1999	Proudman Oceanographic Laboratory, England
UCSD/SIO	Suzanne Lyons	Ph.D. candidate		
University of New Sou	Paul Tregoning (SIO)	Ph.D.	1994	
UNM	Nancy Natek	BS	2001	
UNM	Chloe Peterson	current work-study		
UNM	David Hayes	current work-study		
UNR	Dr. Mark Petersen	Post-doc	1992-1993	Research Scientist, USGS, Golden, CO
UNR	Feng Su	Post-doc		Research Assistant Professor at the Nevada Seismological Laboratory
UNR	Guang Yu	MS or PhD	1995	Computer Programmer in Minneapolis, Minnesota
UNR	Mark Stirling	Ph.D.	1998	IGNS, Wellington, New Zealand
UNR	Yajie Lee	MS or PhD	1998	Consultant in URS Corporation, Los Angeles
UNR	Yuehua Zeng	Post-doc		Research Associate Professor at the Nevada Seismological Laborator
USC	Allan Tucker	MS	1999	U. S. Air Force
USC	An Linji	Ph.D	1995	Exxon Research
USC	Avijit Chakraborty	Ph.D.	1996	Intarka Co., Calcutta, India

USC	David Bowman	Ph.D.	1999	Assistant Professor, California State University Fullerton
USC	David Scott	Post-Doc		Lecturer, University College London
USC	Donovan Stevens	SCEC summer intern		
USC	Joyjeet Bhowmik	M.S.	1995	Hewlett-Packard, San Jose, CA.
USC	Kim Schramm	M.S	2000	U. Texas, El Paso; now at Northwestern University, Evanston, IL.
USC	Kristin Weaver	MS	2000	William Lettis and Associates
USC	Michelle Robertson	MS	1994	Reaearch Technician, Wellington New Zealand
USC	Nicola Godfrey	post-doc	1997-2000	Landmark Graphics, Ltd., London, England
USC	Sandra Steacy	Ph.D.	1992	Lecturer, University of Northern Ireland, Colerain
USC	Shari Christofferson	MS	2002	USC
USC	Y. Huang	Ph.D.	1999	Physics Department
USC	Yueqiang Huang	Post-doc		a software company
USC	Yunfeng Liu	Ph.D.	in progress	
USC	Zhigang Peng	Ph.D.	in progress	
USGS, Pasadena	Matt Gerstenberger (ETH-Zürich), a student of Stefan Wiemer			
USGS, Pasadena	Jeanne Hardebeck (UCSD), a postdoc with Peter Shearer.			

Appendix B (Undergraduates)

YEAR	First	Last	UG institution	Mentor	Mentor Inst.
2001	Keegan	Delaney	Virginia Tech	Tom Jordan	USC
2001	Stacey	Martin Servito	Nowrosjee Wadia College	Susan Hough	USGS
2001	Danielle	Verdugo	Fullerton College	Susan Owen	
2000	Allison	Jacobs	University of California, San Diego	David T. Sandwell	Scripps Institution of Oceanography, UCSD
2000	Clay	Stevens	California State University, Northridge	Doug Yule	California State University Northridge
2000	Marie	Ammerman	UC Santa Barbara	Ralph Archuleta	UC Santa Barbara
2000	Teresa	Baker	Massachusetts Institute of Technology-YES	Susan Owen	University of Southern California
2000	Alexandra	Jordan	University of Southern California	Mark Benthien	USC
2000	Kevin	Mass	Whittier College	Jan Vermilye	Whittier College
2000	Nancy	Natek	The University of New Mexico	Dr. Mousumi Roy	The University of New Mexico
2000	Tracy	Pattelena	Pasadena City College	Kim Olsen and David Okaya	Institute for Crustal Studies, UC Santa Barbara and USC (respectively)
2000	Daniel	Raymond	University of California, Irvine	Dr. Lisa B. Grant	University of California, Irvine
2000	Kathryn	Van Roosendaal	California State University	Bob de Groot	
1999	Natanya	Black	University of California Santa Barbara	Tom Rockwell	San Diego State University
1999	Debra	Einstein	University of California, Irvine	Mark Legg	Legg Geophysical
1999	Marie	Herrera Adsetts	University of California, Santa Barbara	Bruce P. Luyendyk	University of California, Santa Barbara
1999	Grant	Kier	University of Colorado	Karl Mueller	University of Colorado
1999	Christopher	Lynch	San Diego State University	Steven M. Day	San Diego State University
1999	Nathan	Robison	University of Nevada	Dr. John Anderson	UNR Seismology Laboratory
1999	Kelly	Schmoker	Cal. State San Bernardino	Dr. Sally McGill	CSUSB
1999	Ashley	Streig	Occidental College	Kerry Sieh/Doug Yule	California Institute of Technology
1999	Kathryn	van Roosendaal	California State University Northridge	David Okaya	University of Southern California

1999 Adam	Webber	University of California, Santa Barbara	Dr. E. A. Keller	University of California, Santa Barbara
1998 Safaa	Dergham	CSU of Long Beach	Sally McGill	CSU San Bernardino
1998 Leland	Green	UC Santa Barbara	Craig Nicholson	UC Santa Barbara
1998 Lowell	Kessel	UC Santa Barbara	Arthur Sylvester	UC Santa Barbara
1998 Jacqueline	Moccand	USC	Ann Blythe	USC
1998 Tracy	Pattelena	Pasadena City College	David Okaya and Nikki Godfrey	USC
1998 Justin	Rubinstein	UCLA	Paul Davis	UCLA
1998 Javier	Santillan	UC Santa Barbara	Jaime Steidl	University of California at Santa Barbara
1998 Lisa	Sarma	Columbia University School of Engineering and Applied Science	Tom Heaton	Caltech
1997 Carmen	Alex	UC Santa Barbara	Kim Olsen	UC Santa Barbara
1997 Wendy	Dailey	Cal Poly Pomona	C. Theodoropolis	Cal Poly Pomona
1997 Neil	Morgan	UC Santa Barbara	Ralph Archuleta	UC Santa Barbara
1997 Erik	Ronald	UC Santa Barbara	Ed Keller (Larry Gurrola, Molly Trecker)	UC Santa Barbara
1997 Ryan	Smith	University of Southern California	David Okaya	University of Southern California
1997 Jana Juracy	Soares Lopez	CICESE	Steve Day	San Diego State
1997 Allan	Tucker	University of Southern California	Bill Doll	Oak Ridge National Lab
1996 Erik	Bartsch	University of California, Santa Barbara	Bruce Luyendyk	University of California Santa Barbara
1996 Dawn	Cheng	University of Southern California	Yan Xiao,	University of Southern California
1996 Marcy	Davis	University of California, Santa Barbara	Larry Gurrola, Edward Keller,	University of California Santa Barbara
1996 Margaret	Glasscoe	University of Southern California	Andrea Donnellan	Jet Propulsion Laboratory
1996 Mandy	Johnson	University of Southern California	Andrew Meigs, James Dolan	University of Southern California
1996 Gretchen	Mullendore	Orange Coast College, UC Santa Barbara	Ralph Archuleta,	University of California Santa Barbara
1996 Donna	Rathman	Irvine Valley College / University of California Irvine	Ann Tanouye	Governor's Office of Emergency Services
1996 Jeni	Tucker	California State University, San Bernardino	Sally McGill, Tim Ross,	California State University, San Bernardino
1996 Allan	Tucker	University of Southern California	William Doll	Oak Ridge National Laboratory

1996 Carmen	von Stein	Western Washington University	Thomas Rockwell	San Diego State University
1995 Windy	Brimer	UC Santa Barbara	Marc Kammerling	UC Santa Barbara
1995 Andrew	Byers	UC Santa Barbara	Jamie Steidl,Ralph Archuleta	UC Santa Barbara
1995 Heather	Hodgetts	University of Southern California	Rachel Abercrombie	University of Southern California
1995 Mandy	Johnson	University of Southern California	David Jackson	UCLA
1995 Jason	McKenna	UC Santa Barbara	Fabian Bonilla, Jamie Steidl, and Ralph Archuleta	UC Santa Barbara
1995 Susannah	Pazdral	Wellesley College	Marc Legg	ACTA, Inc.
1995 Ryan	Smith	University of Southern California	Michelle Robertson	University of Southern California
1995 Donovan	Stevens	Caltech	James Dolan	University of Southern California
1995 Carmen	von Stein	Central Washington University	Lisa Grant	Woodward-Clyde
1995 Mike	Watkins	UC Santa Barbara	Kim Olsen	UC Santa Barbara
1995 Isabelle	Wicks	University of Southern California	Charles Sammis	University of Southern California
1994 Mark	Benthien	University of California Los Angeles	Paul Davis	University of California Los Angeles
1994 Diem-Phuong	Do	University of California Los Angeles	Mladen Vucetic	University of California Los Angeles
1994 Geoffrey	Ely	University of California Santa Barbara	Craig Nicholson	University of California Santa Barbara
1994 Katharine	Hsu	University of California, Los Angeles	Mladen Vucetic	University of California, Los Angeles
1994 Joe	Jarboe	University of California San Diego	Duncan Agnew	University of California San Diego
1994 Kristien	King	University of California Davis	Thomas Henyey and Yong-Gong Li	University of Southern California
1994 John	Marquis	California Institute of Technology	Egill Hauksson	California Institute of Technology
1994 Erick	Mc Wayne	University of California, Santa Barbara	Craig Nicholson	University of California, Santa Barbara
1994 Matthew	Ragan	University of Southern California	Rachel Abercrombie	University of Southern California
1994 Damien	Sullivan	California Institute of Technology	Egill Hauksson	California Institute of Technology

1994 Christopher	Sykes	San Diego State University	Tom Rockwell, Lisa Grant, John Waggoner	San Diego State University
1994 Kimberly	Thorup	San Diego State University	Tom Rockwell and George Kennedy	San Diego State University
1994 Chris	Walls	Central Washington University	Scott Lindvall	

Appendix C

List of CenterFaculty (and Equivalent) Participants During Year 11

I. Receiving Center Support

PI	AFFILIATION		
Agnew, Duncan	UCSD		
Anderson, John	UNR		
Anderson, Greg	USC		
Archuleta, Ralph	UCSB		
Arrowsmith, Ramon	Arizona State		
Ben-Zion, Yehuda	USC		
Bock, Yehuda	UCSD		
Brune, Jim	UNR		
Caffee, Mark	LLNL		
Clayton, Rob	Caltech		
Cooke	Mass/Amherst		
Davis, Paul	UCLA		
Day, Steve	SDSU		
Dolan, James	USC		
Dong, Danan	JPL		
Field, Ned	USC		
Foxall, Bill	LLNL		
Grant, Lisa	UC-Irvine		
Graves, rob	URS Group Inc.		
Hager, Brad	MIT		
Hardebeck. Jeanne	UCSD		
Hauksson, Egill	Caltech		
Helmberger, Don	Caltech		
Henyey, Tom	USC		
Hudnut, Ken	USGS		
Humphreys, Gene	Oregon		
Jackson, Dave	UCLA		
Kagan, Yan	UCLA		
Kamerling, Marc	UCSB		
Kanamori, Hiroo	Caltech		
King, Bob	MIT		
Kohler, Monica	UCLA		
Lavallee, Daniel	UCSB		
Li, Yong-Gang	USC		
Lindvall, Scott	William Lettis & Assoc.		
Liu, Peng-cheng	UCSB		
Magistrale, Harold	SDSU		
McGill, Sally	Cal State, San Bernardino		
Minster, Bernard	UCSD		
Mueller, Karl	Colorado		
Okaya, David	USC		
Olsen, Kim	UCSB		
Owen, Sue	USC		
Rice, Jim	Harvard		
Rockwell, Tom	SDSU		

Roy, Mousumi	New Mexico		
Rubin, Charlie	CWU		
Sammis, Charles	USC		
Seeber, Nano	Columbia		
Seitz, Gordon	LLNL		
Shaw, Bruce	Columbia		
Shaw, John	Harvard		
Shen, Zheng-kang	UCLA		
Sieh, Kerry	Caltech		
Simila, Gerry	CSUN		
Simons, Mark	Caltech		
Sorlien, Chris	UCSB		
Steidl, Jamie	UCSB		
Sykes, Lynn	Columbia		
Vermilye, Jan	Whittier		
Vidale, John	UCLA		
Ward, Steve	UCSC		
Wesnousky, Steve	UNR		
Wyatt, Frank	UCSD		
Wyss, Max	Alaska		
Yeats, Bob	Oregon State		
Yule, Doug	CSUN		
Zeng, Yue-hua	UNR		
Zhu, Lupei	USC		

Appendix D

Biographical Information on New Investigators

Note: No new investigators in Year 11.

Appendix E

List of Awards and Honors

Thomas H. Jordan: Elected to American Philosophical Society
Charles G. Sammis: USC Outstanding Research Award

Appendix G

Summary Table

Number of Participating Institutions	45
Number of Partners	20
Total Leveraged Support	$40M
Total Number of Participants	5,000

Note: The SCEC data centers (seismology, strong motion, and geodesy) are regularly used by approximately 5,000 scientists and students each year. It is impossible to list all the users.

Appendix F
SCEC Advisory Council Final Report

December 6, 2001

Subject: SCEC Advisory Committee Report, 2001 SCEC Annual Meeting, September, 2001, Oxnard, California

Members present:

Robert B. Smith, Chair, University of Utah
Lloyd Cluff, PG&E
C. B. Crouse, URS
Jim Dieterich, USGS
Jack Moehle, PEER, UC Berkeley
Tom Jordan, MIT
Barbara Romanowicz, UC Berkeley
Kaye Shedlock, USGS
Susan Tubessing, EERI

First we want to congratulate SCECI on its very successful integrated earthquake research initiative and related outreach and education programs. The decade record of this organization is exemplary in its contributions to national efforts in earthquake hazard assessment and hazard mitigation and in particular to its application in Southern California community.

SCEC has set a high standard for academic and emergency management organizations in all categories of earthquake science and related safety mitigation. Moreover its outreach and education programs are admired by national and state programs for their careful organization and effectiveness.

The long term goal of the Advisory Committee (AC) has been to give independent advice to SCEC on a variety of topics ranging from management to leadership to science implementation. Our primarily input to the SCEC Director has been by an annual report prepared following the annual meeting as well as advice given in personal contacts with SCEC's management throughout the year. The annual reports were also copied to the NSF and USGS program directors responsible for SCEC budget oversight.

One of the reasons for the Advisory Committees active role, was that we as individual scientists, engineers, etc. were interested both scientifically and curious about SCEC's research efforts, how it distributed its information, and how the user community used such information. As a result, the AC was notably aggressive in its inquiries and we believe influential in providing objective and independent advice regardless of how SCEC management felt.

We particularly note that the NSF Science and Technology Center review of SCEC pointed out the independence and effectiveness of the SCEC Advisory Committee in its advisory role. We recommend that this tradition be continued in SCEC2.

Additional Comments:

An additional topic that should be considered by SCEC2 management is to develop a diversity task force that is broadened and emphasized in the SCEC2 organization.

We caution SCEC2 on the sense of expectations of its existing working groups to a similar role in light of the new and likely reduced budget, i.e. SCEC2 appears to be broadening its scope but has less resources to accomplish them. This will require leadership and prioritization of SCEC to attain its programmatic goals. The Advisory Committee can be helpful in providing independent advice on these issues.

We also caution that SCEC's information, i.e., maps, reports, talks, etc. can have a major economic impact. To avoid liability and scientific perception issues, quality assurance of SCEC products must be guaranteed. With a broader audience and higher expectations of SCEC2 a strong Q&A policy is needed to assure data quality and product usefulness.

Integration and project coordination across SCEC disciplines must be continued and strengthened. This is particularly necessary for the success of the Outreach and Education program.

Data base systems become more and more important as organizations mature. This is of course because of the increased volume and need for reliable access to its data. SCEC should consider its use of the GIS information storage and delivery systems for all of its products, i.e., data, maps, reports, etc. Local, state and federal communities have embraced GIS, for good or worse, as their data standard and SCEC must be compatible in its data storage and delivery mechanisms to these groups via GIS systems.

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Salt Lake City, Utah 84112

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email: rbsmith@mines.utah.edu

Appendix H1
SCEC/STC Faculty

Faculty	Institution	Department
Abercrombie, Rachel	Boston University	Earth Sciences
Agnew, Duncan	University of California, San Diego	Scripps Institute of Oceanography
Aki, Keiiti	University of Southern California	Earth Sciences
Anderson, John	University of Nevada, Reno	Seismological Laboratory
Archuleta, Ralph	University of California, Santa Barbara	Institute for Crustal Studies
Arrowsmith, Ramon	Arizona State University	Geology
Ben-Zion, Yehuda	University of Southern California	Earth Sciences
Beroza, Gregory	Stanford University	Geophysics
Biasi, Glen	University of Nevada, Reno	Seismological Lab
Bielak, Jacobo	Carnegie Mellon University	Civil & Environmental Eng
Bock, Yehuda	University of California, San Diego	Scripps Institute of Oceanography
Brune, James	University of Nevada, Reno	Seismological Laboratory
Burbank, Douglas	University of California, Santa Barbara	Institute of Crustal Studies
Burgmann, Roland	University of California, Berkeley	Geology & Geophysics
Clayton, Robert	California Institute of Technology	Seismological Lab
Cooke, Michele	University of Massachusetts, Amherst	Geoscience
Cornell, Allin	Stanford University	Civil and Environmental Engineering
Davis, Paul	University of California, Los Angeles	Earth & Space Sciences
Day, Steven	San Diego State University	Geological Sciences
Dolan, James	University of Southern California	Earth Sciences
Donnellan, Andrea	University of Southern California	Earth Sciences
Dravinski, Marijan	University of Southern California	Mechanical Engineering
Dreger, Doug	University of California, Berkeley	Seismological Laboratory
Ekstrom, Goran	Harvard University	Earth & Planetary Sciences
Evans, James	Utah State University	Geology
Fialko, Yuri	University of California, San Diego	Institute of Geophysics and Planetary Physics
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Hager, Brad	Massachusetts Institute of Technology	Earth, Atmospheric, and Planetary Sciences
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Hauksson, Egill	California Institute of Technology	Seismological Laboratory
Heaton, Thomas	California Institute of Technology	Geological & Planetary Sciences
Helmberger, Don	California Institute of Technology	Geologic and Planetary Sciences
Henyey, Thomas	University of Southern California	Earth Sciences
Herring, Tom	Massachusetts Institute of Technology	Earth, Atmospheric, and Planetary Sciences
Humphreys, Eugene	University of Oregon	Geological Sciences
Jackson, Dave	University of California, Los Angeles	Earth & Space Sciences
Johnson, Arvid	Purdue University	Earth and Atmospheric Sciences
Jordan, Thomas	University of Southern California	Earth Sciences
Kanamori, Hiroo	California Institute of Technology	Seismological Laboratory
Keller, Ed	University of California, Santa Barbara	Institute for Crustal Studies
Kellogg, Louise	University of California, Davis	Geology
King, R.W.	Massachusetts Institute of Technology	Earth, Atmospheric & Planetary Sciences
Klein, William	Boston University	Physics
Knopoff, Leon	University of California, Los Angeles	Institute of Geophysics and Planetary Physics
Lay, Thorne	University of California, Santa Cruz	Earth Science
Li, Yong-Gang	University of Southern California	Earth Sciences
Louie, John	University of Nevada, Reno	Seismological Laboratory
Luyendyk, Bruce	University of California, Santa Barbara	Geological Sciences
Lyzenga, Greg	Harvey Mudd College	Physics
Magistrale, Harold	San Diego State University	Geological Sciences
Marone, Chris	Pennsylvania State University	Geosciences
Martin, Geoffrey	University of Southern California	Civil Engineering
McGill, Sally	California State University, San Bernardino	Geological Sciences
McNally, Karen	University of California, Santa Cruz	Earth Sciences Board of Studies
Meigs, Andrew	Oregon State University	Geosciences
Mellors, Robert	San Diego State University	Geological Sciences
Miller, Meghan	Central Washington Universtiy	Geology
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Morgan, Julia	Rice University	Earth Science
Mueller, Karl	Colorado University	Geological Sciences

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Okaya, David	University of Southern California	Earth Sciences
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Oskin, Michael	University of California, Santa Barbara	Institute for Crustal Studies
Owen, Susan	University of Southern California	Earth Sciences
Park, Stephen	University of California, Riverside	Earth Sciences
Reilinger, Robert	Massachusetts Institute of Technology	Earth, Atmospheric, and Planatery Sciences
Rice, James	Harvard University	Earth & Planetary Sciences
Rockwell, Thomas	San Diego State University	Geological Sciences
Roy, Mousumi	New Mexico University	Earth & Planetary Sciences
Rubin, Charlie	Central Washington Universtiy	Geology
Rundle, John	University of Colorado	Physics
Sammis, Charles	University of Southern California	Earth Sciences
Sandwell, David	University of California, San Diego	Scripps Institute of Oceanography
Scholz, Christopher	Columbia University	Lamont-Doherty Earth Observatory
Segall, Paul	Stanford University	Geophysics
Shaw, John	Harvard University	Earth and Planetary Sciences
Shearer, Peter	University of California, San Diego	Institute of Geophysics and Planetary Physics
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Simila, Gerald	California State University, Northridge	Geological Sciences
Simons, Mark	California Institute of Technology	Seismological Laboratory
Spotila, James	Virginia Technical Institute	Geological Sciences
Stock, Joann	California Institute of Technology	Geology & Planetary Sciences
Suppe, John	Princeton University	Geological & Geophysical Science
Sykes, Lynn	Columbia University	Lamont-Doherty Earth Observatory
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Templeton, Mary	California State Univeristy, Fullerton	Earth and Environmental Science
Teng, Ta-liang	University of Southern California	Earth Sciences
Tromp, Jeroen	California Institute of Technology	Seismological Laboratory
Tullis, Terry	Brown University	Geological Sciences
Vermilye, Jan	Whittier College	Earth & Environmental Sciences
Vidale, John	University of California, Los Angeles	Earth & Space Sciences
Vucetic, Mladen	University of California, Los Angeles	Civil Engineering
Ward, Steven	University of California, Santa Cruz	Institute of Tectonics
Weldon, Ray	University of Oregon	Geological Sciences
Wesnousky, Steve	University of Nevada, Reno	Center for Neotectonic Studies
Wyss, Max	Alaska University	Geophysical Institute
Yeats, Robert	Oregon State	Geosicences
Yule, Doug	California State University, Northridge	Geological Sciences
Zebker, Howard	Stanford University	Electrical Engineering Labs
Zeng, Yuehua	University of Nevada, Reno	Seismological Laboratory
Zhu, Lupei	St. Louis Univeristy	Earth and Atmospheric Sciences