Awards Administered 2006-2007

Archuleta
National Science Foundation
CMS-0201264
COSMOS Virtual Data Center
09/01/02-08/31/07 ARN05
$397,395
Agency: COSMOS
2003-02
COSMOS Virtual Data Center
09/01//02-08/31/08 ARR01
$75,000
California Dept. of Conservation-California Geological Survey
1005-807 & 1005-822
07/01/05-12/31/07 ARC01
$30,000
The proposal requests support to continue development of the COSMOS Virtual Strong-motion Data Center — COSMOS VDC — an unrestricted, Web-based, interactive strong ground motion data resource for the practicing earthquake engineering, emergency response, research, and other earthquake professional communities. The major goal of the VDC is to expand and significantly improve the accessibility and the use of all strong-motion records collected by the ever-growing number of US and international organizations (e.g. CDMG, USGS, ACOE, USBR, USC, SCEC, Japan KNET, Taiwan CWB, and others, including small networks operated by universities). The VDC operates under the direction of The Consortium of Organizations for Strong-Motion Observation Systems (http://www.cosmos-eq.org/). The COSMOS structure enables the VDC to respond to both the organizations that collect the data and the users (academic and professional) of the data; and ensures that the VDC evolves so that it remains responsive to the community of engineers, scientists and other users of strong-motion data. This proposal is focused on advancing the science of interactive, Web-based analysis, dissemination, and use of strong-motion data for the direct benefit of the engineering and scientific communities who use the data to mitigate and understand the nature of earthquake hazards. The proposed research will advance the capability of the COSMOS VDC by further developing the proven concept of a virtual data center and its important role in coordinating the access and dissemination of strong-motion data.

The VDC provides a very cost-effective way to leverage the data processing and management resources of all of the participating agencies and organizations. The VDC continually develops, updates, and maintains a sophisticated parameter metadata environment in a state-of-the-art relational database. This permits the user to interactively query, search, retrieve and analyze strong-motion information using the latest developments in Web technology. At the same time, the accelerogram data and other data products are stored and maintained either by the collecting organization, or by the VDC, if the collecting organization so chooses, but in such a way as to be transparent to the user, thus the 'virtual' nature of the portal to the data provided by the VDC. The direct responsibility for data collection, processing, basic quality control, and storage remains primarily in the hands of the collecting agencies and organizations. The user can thus have confidence that the data are the most current available. This approach provides a major step forward in improving accessibility of the data to the research, practicing, and emergency response communities for purposes of earthquake hazard mitigation.

The funding sought by this proposal will be used together with funds provided by COSMOS to: 1) advance Web-based interfaces with the Advanced National Seismic System (ANSS) data management system; 2) advance methods for augmenting the existing VDC metadata database; 3) advance Web-based methods to facilitate efficient query and retrieval of a variety of event, station, and processed time history information; 4) develop Web-based methods for dissemination of information according to user selectable format, processing and visualization; 5) facilitate development of COSMOS standards for data formats and processing; 6) advance Web-based interfaces with other databases to enhance the metadata on earthquakes, recording site characteristics, and other relevant information for the VDC; 7) enhance Web-based interfaces and links for replication sites; and 8) advance Web-based interfaces with geotechnical databases.

Archuleta
Carlson
Department of Interior
06HQGR0046 ARU01
Model Uncertainty in Earthquake Hazard Analysis
01/01/06-12/31/07
$60,000
Rigorous methodology in Probabilistic Seismic Hazard Analysis (PSHA) requires fully accounting for model uncertainty. PSHA is characterized by deep uncertainty, for not only is there parameter uncertainty regarding the values of various parameters needed to estimate hazard, there is also model uncertainty stemming from uncertainty regarding the mechanism generating risk. We have diagnosed a number of unintended biases inherent in the current formulation of model uncertainty in PSHA. While there is much research into many of the specific ingredients that make up a hazard estimate, a thorough review of the statistical methods for combining probability distributions has not been yet undertaken. In particular, the current method used by the 2002 Working Group on California Earthquake Probabilities (WG02) to combine the probability distributions given by multiple models has several adverse effects on their result. A rigorous treatment of model uncertainty will eliminate sources of bias inherent in their method; in addition, properly accounting for model dependencies will reduce the uncertainty in the final result. We propose to develop a methodology with a rigorous statistical foundation that fully incorporates model uncertainty. Such a methodology will allow for the most precise formulation of hazard that the data allows, which is key in reducing earthquake losses in Southern California and beyond.

In addition to providing a robust statistical foundation for dealing with model uncertainty, we will also be addressing the more general problem of uncertainty propagation relating to the earthquake problem. In particular, we seek to quantify the level of uncertainty present in kinematic inversions of the earthquake source. We propose to use the mathematical tools available from control and dynamical systems to obtain a general method for quantifying the uncertainty and sensitivity of kinematic solutions. Such a method would give a) a measure of which areas of the fault are well-constrained given the data, b) a measure of how much the result is dependent on the constraints introduced to stabilize the problem, and c) the sensitivity of the results to different parts of the data. Our results will clarify why different inversion techniques often give quite different results, as well as make clear the true resolution of source parameters that we have given seismic data from a given earthquake.

Archuleta
Los Alamos National Security, LLC

34895-002-06 ARS07/ ARS08
Heterogeneity of Stress in the Crust and Its Effect on Earthquake Rupture
06/01/06-9/30/07
$32,900
It is now well established that heterogeneities in tractions along faults play a significant role in the dynamics of earthquake rupture, in the resulting seismic radiation, and even whether an earthquake, once nucleated, is small or grows into a major event. While the importance of this heterogeneity is established, there is little understanding in how it arises and what are reasonable spatial distributions of the tractions. Understanding the causes and character of heterogeneous tractions on faults prior to major earthquakes is a significant unsolved problem in our understanding of earthquake source physics. We propose to use the most recent results from scattering theory about the spatial variation in crustal physical properties to define plausible spatial variations of tractions on faults. These tractions will be used as input to codes that simulate dynamic earthquake ruptures. We plan to investigate whether the heterogeneous tractions estimated from using scattering observations are sufficient to explain the observed ground motion time histories and inferred distributions of rupture velocity and slip distributions found for past earthquakes.

Archuleta
Liu
National Science Foundation
0512000-EAR ARN01
Resolution, Robustness and Dynamics Based on Inversions of Seismic and Geodetic Data of the 2004 Parkfield Earthquake
7/1/08-6/30/08
$289,500
The ultimate result is to determine why the Parkfield earthquake behaved as it did. Kinematic models provide only a glimpse of the process. To understand the physics of the earthquake, the evolution of faulting must be spontaneous, controlled by the stresses and the constitutive law for friction. Why did the 2004 Parkfield earthquake nucleate near Gold Hill and rupture northwest? The 1966 and 1934 Parkfield earthquakes nucleated near Middle Mountain and ruptured southeast. Are the regions of high stress drop consistent with areas inferred from seismicity and b-value studies? Would a small perturbation to the initial stress distribution allow for a rupture to nucleate at Middle Mountain and propagate southeast or perhaps nucleate at some other location? Did the three prior M>4 earthquakes influence the stress pattern? Is the San Andreas Fault weak? Dynamic modeling will provide some answers, but to get to the dynamics one must have kinematic parameters that are robust with quantifiable uncertainties.

The data from the 2004 Parkfield MW 6.0 earthquake offer an unprecedented opportunity to dissect the dynamics of the earthquake process. In order to set the initial conditions for dynamic modeling, the seismic and geodetic data must first be inverted to find the kinematic parameters that describe the faulting. Within 20 km of the fault there are 56 three-component strong motion records plus a dense 13-element array (UPSAR) combined with 13 continuous GPS recordings and 10 or more campaign sites. Because the Parkfield earthquake was a prediction experiment, and Middle Mountain is the site for EarthScope's SAFOD project, there has been a wide range of studies that characterize the velocity and attenuation structure and the seismicity for this section of the San Andreas Fault. Consequently with the mainshock data and characterization of the medium, we have the essential elements to invert for the earthquake kinematics.

Archuleta

National Science Foundation
EAR-0646274 ARN08
Numerical Modeling of Earthquake Source Dynamics
03/01/07-02/09/08
$19,608
The purpose of the workshop is to bring together the various researchers from the United States, Asia and Europe who use numerical simulations to investigate dynamics of earthquake ruptures. The three days of talks and discussion will cover a full range of topics related to earthquake dynamics: stress distributions on the fault, rupture history including nucleation and arrest, constitutive laws for friction, role of heterogeneity, energy budget and seismic radiation, numerical techniques, and simulations of dynamics for past earthquakes. Dynamics of the earthquake source is the natural evolution in our understanding of the source from point source body force equivalents, to centroid moment tensor to finitefault kinematic simulations. Understanding the dynamics of earthquakes will eventually lead to physical explanations for fundamental observations in seismology such as Gutenberg-Richter statistics, variability of stress drops, radiated energy, heat flow paradox, subshear and supershear rupture velocity, locus of earthquake hypocenters and correlation among the kinematic parameters. Although earthquake dynamic modeling (Kostrov, 1964) has been around as long as body force equivalents (Maruyama, 1963; Burridge and Knopoff, 1964) and kinematic modeling (Haskell, 1964), it has only been in the past decade that the computational hardware has allowed for simulations using a variety of numerical methods. (Many of the early seminal papers—numerical and theoretical—that were the starting points for the current research are referenced in Das and Kostrov, 1988.) Obviously the dynamical models represent more accurately the physics of the earthquake process. However, there are many facets of the problem that need to be explored to understand how and why a rupture spontaneously propagates. Of course, these physics based simulations will become the foundation for ground motion predictions. The number of investigators using dynamic simulations to explore the physics of earthquakes and their subsequent ground motions is rapidly expanding both in the US and elsewhere. This workshop allows the US scientists an efficient and effective method for learning about successful research approaches and potential pitfalls. The attendees from Europe and Asia are the leading researchers in earthquake source dynamics and numerical methods. There are coordinated efforts in the US (Harris and Archuleta, 2004) as well as in Europe (http://www.spice-rtn.org/scope/dynamicrupture/) and in Japan (http://www.eri.u-tokyo.ac.jp/daidai/index-main-Eng.html). While US attendees certainly have a lot to share, we also have a lot to learn. This workshop focused on earthquake dynamics is the ideal venue for doing both.

Becker
National Aeronautics and Space Administration
NNG04GC17G BLF09
Atmospheric Pressure Matrix Assisted Laser Desorption/Ionization Trap Mass Spect
01/15/04-01/14/07
$328,873

Becker
National Aeronautics and Space Administration
NNG04GJ36G BLF06
Traces of Catastrophe at the End Permian
05/01/04-04/30/08
$321,307

Becker
National Aeronautics and Space Administration
NNG06GG87G BLF07
Mars Organic Molecule Analyzer (MOMA)
04/15/06-10/15/07
$263,000

Boles
Israelachvili
American Chemical Society - PRF
PRF# 39823-AC2 BJI01
Dissimilar Mineral Interfaces: Understanding Mica/Quartez Surface Interactions
07/01/2003-08/31/2006
$79,325
We propose a new interdisciplinary project of fundamental experiments on the interactions between quartz and mica separated by thin aqueous films. We seek to understand the cause of ‘pressure solution’, the extraordinary dissolution of quartz in contact with mica which – as inferred from more than 50 years of petrographic observations – is orders of magnitude higher than for quartz-quartz and mica-mica contacts, or for quartz-solution interfaces. Our goal is to simulate mechanical strain and physical-chemical conditions on mica-quartz contacts to establish the effects of crystallography orientation, pressure, temperature, ionic solution, and pH around natural sand formations. The results will be fundamental for understanding various processes such as quartz cementation in hydrocarbon reservoirs, the role of pressure in “pressure solution”, the post-rupture healing of faults, and how dissimilar minerals interact in aqueous solutions. These results will also directly impact other disciplines and phenomena such as mixed colloidal systems and clay-swelling. The experiments will be conducted by an experienced postdoc, using a Surface Forces Apparatus (SFA), whose pioneer is my collaborator, Jacob Israelachvili (an expert on intermolecular force measurements). Experimentally modified surfaces will also be studied with the AFM. Recently, we have been able to acquire synthetically grown, micron-thick flat quartz sheets, in addition to the traditional muscovite used in the SFA-experiments. Our preliminary experiments, never before attempted, indicate that when these *dissimilar* surfaces are pressed together in aqueous solution, the quartz dissolves at a remarkable rate, leaving us confident of our ability to quantitatively investigate the important variables in the quartz-mica system.

Boles
Israelachvili
National Science Foundation
EAR-0342796 BJN01
Understanding the Role of Clay Mineral Surface Interactions in Pressure Solution
07/01/04-06-30/07
$152,345
Seismic microzonation is "the process of determining absolute or relative seismic hazard at many sites accounting for the effects of geologic and topographic amplification of motion and of soil stability and liquefaction, for the purpose of delineating seismic micro zones in order to reduce damage to human life and property resulting from earthquakes." (EERI, 1984). The intensity of the ground motion depends on the seismic source-earthquake magnitude distance from the seismic source, style of faulting-together with

local soil conditions, topography and geological conditions. The spatial variability of the ground motion, even over relatively short distances of hundreds of meters, is difficult to predict. Peak amplitudes of acceleration or velocity can vary by a factor of five or more over distances of several hundred meters or less. Quantifying how factors such as soft soils, topography or geological conditions can affect the ground motion over small distances requires a large capital investment for instrumentation and an active seismic area that can provide a variety of different sources. The Yokohama 150 element high-density seismic array offers a unique opportunity to study the spatial variation of ground motion. In 1997 Yokohama established a dense accelerometer array to be used for mitigation of earthquake losses and real-time damage assessment. The array is within a 434 km area with an average station spacing of approximately 2 km, with many stations more closely spaced. In addition to the surface sites there are nine borehole sites, three of which are at depths around 62 m. We propose to analyze data from 41 earthquakes currently recorded on this array. Because of the density of stations we can correlate ground motion parameters such as spectral amplification, Arias intensity, duration, cumulative absolute velocity, peak ground acceleration and peak ground velocity with geological and geographical features such as basin depth, distance to basin edges and local shear wave velocity. Rarely are there sufficient data to analyze the statistical variation in ground motion parameters over such a confined area. The results of the analysis should provide insights into how different geological or geographical features affect ground motion. Because of density of stations provided by the Yokohama array we can quantify the coherence of each parameter for different distances and correlate the same parameters with different geological conditions. With the variety of different earthquake sources we will compare ground motion from seismic sources that are crustal (less than 20 km deep) and those that are in the subducting slab (50-100 km deep). In order to predict realistic ground motion that can be used at the spatial dimensions of urban areas one must have a quantitative assessment of the natural variability due to the site response, even for sites that have similar local geology. Using the data from the Yokohama dense array we plan to quantify the variably that site response has on predicted ground motion.

Burbank
National Science Foundation
EAR-0117242 BDN03
Collaborative Proposal: Scaling and Displacement Relationships for Thrust Faults
04/01/2001-12/31/06
$214,464
We have undertaken research on scaling (displacement-length) relationships in thrust faults and on the ways in which thrust faults link, anastomose, and evolve through time. The bulk of the fieldwork is focused on the Ostler Fault system in the South Island of New Zealand and was begun in mid-January, 2002. The initial fieldwork involved the integration of detailed topographic surveying of scarp morphologies, measurement of offset and deformed geomorphic features, subsurface surveys of displaced structural markers, and geochronologic studies of offset markers. The topographic surveys were conducted with differential GPS augmented by analysis of a high-resolution TOPSAR DEM. These topographic data were integrated with co-registered subsurface data, primarily derived from ground-penetrating radar surveys and electrical resistivity studies.

The next field season will involve a focus on structural and geomorphic mapping, rather than on scaling parameters of faulting. We have discovered unusual (and unusually well displayed) structural geometries with elongate rotated back limbs and strongly folded forelimbs on thrust anticlines. Our goal this year is to map the large scale geometry of the fault zone along its 50-km-long expression, document the structural style and its potential dependence on the rock which is being deformed, and analyze the geomorphic response to these growing, linking, and interacting folds and faults.

Burbank
National Science Foundation
EAR-0196414 BDN02
Collaborative Research: Geomorphic-Geodynamic Coupling at the Orogen Scale: Himalayan Transec in Central Nepal
03/15/01-12/31/08
$473,778
One of the most provocative-yet largely untested-recent hypotheses concerning orogenic evolution is that regional variations in climate strongly influence spatial variations in the style and magnitude of deformation across an actively deforming orogen. Recent progress in quantifying rates of both tectonic and geomorphic processes and in modeling surface and lithospheric processes sets the stage for an integrated, quantitative, field- and model-based investigation of the interactions and feedbacks between geomorphic, climatic, and tectonic processes. We propose to examine these interactions where they are likely to be most clearly expressed: the Nepalese Himalaya. Not only in this the quintessential collisional orogenic belt, but its topographic growth and erosional history have been suggested as key controls on global climatic changes. Our integrated study focuses on a major transverse catchment, stretching from the edge of the Tibetan Plateau to the foreland and traversing some of the highest topography in the world. This transect spans the major structural elements of the Himalaya, as well as monsoon-to-rainshadow climatic conditions. We bring together expertise in process-based geomorphology, glaciology, climatology, structural geology, thermochronology, cosmogenic radionuclide dating, modeling, and documentary film making for a multi-pronged approach intended to evaluate one overarching, but largely untested hypothesis:

- Rates of erosion vary spatially as a function of climate and this spatial variability in erosion controls the partitioning of deformation within an orogen.
-

Furthermore, we will collect data to assess the following related, but subsidiary hypotheses:

- The erosional response to rapid lateral advection of crust across a basement ramp-crustal scale fault-bend folding, for example-creates erosion rates that are nearly equal across the entire topographic escarpment of the Himalaya, ranging from 8 km to 1 km in elevation.
- Above a certain threshold erosion rate, the topography attains a dynamic ‘equilibrium’ or steady state that is independent of erosion rate.
- Topographic characteristics (relief, slope angles, normalized river gradients) correlate more strongly with erosion rates than they do with variations in climate or lithology.

Despite the broad scope of these hypotheses and the impossibility of resolving all details, we have developed a research strategy that, over a four-year span, will enable us to define the primary characteristics of denudation, rock uplift, climate, and topography across the Himalaya and to calibrate some process-based ‘rules’ for major erosional agents, such as glaciers, rivers, and landslides. A key to success will be the integration of data from diverse subdisciplines (climate, geomorphology, tectonics) at the scale both of intensively monitored subcatchments and of the entire trans-Himalayan catchment. Spanning seven subdisciplines in earth and atmospheric sciences, this project brings together researchers from seven US institutions and three governmental agencies in Nepal.

Burbank
National Aeronautics and Space Administration
NAG5-13758 BDF02
Tectonic-Climate Interactions in Active Orogenic Belts: Quantification of the approach to steady-statetopography with SRTM data
10/01/2003-09/30/08
$330,000
Active orogenic mountain belts around the world have been imaged during the SRTM. We propose to utilize the newly acquired topographic data in conjunction with data on the development of drainage networks, magnitude of erosion, patterns of deformation, and the extent of glaciation to address key questions about the topographic evolution of collisional mountain belts. An emerging consensus indicates that topographic steady state is commonly achieved in collisional orogens if rates of deformation are rapid and sustained. In this proposal we will investigate the geomorphic and topographic changes that occur during the transitional phase of a range approaching steady state. We will focus much of this research on drainage networks, because these control the dissection of pre-steady-state topography and modulate hillslope responses to base-level changes. In the central Tien Shan, we have found an outstanding site where fluvial channel growth can be traced from its incipient stages to full development and where network growth through time, interactions with active folds and thrust faults, and the impact of contrasting initial slopes can all be quantified in pre-steady-state conditions.

As dissection increases, changes in hillslope characteristics provide key indices of the evolution of pre-steady-state topography. In the Kyrgyz Range (north Tien Shan), geologic mapping and thermochronology show that denudation increases from <1 km in the east to >4-5 km in the west. This denudation gradient corresponds to a range-scale transition from pre- to nearly complete topographic steady state. We will exploit this spatial gradient to quantify topographic indices of the approach to steady state in both glaciated and non-glaciated terrains.

By combining these two study areas in the Tien Shan, we can quantify both hillslope and fluvial evolution toward steady state. Our research will revolve around the following questions:

- How do drainage networks evolve toward steady state as they interact with active folds and faults?
- What progressive topographic changes occur within a rapidly deforming, but pre-steady-state landscape and at what stage do slopes pass thresholds for widespread bedrock land sliding.
- To what extent can topographic characteristics be used to differentiate between pre-steady-state and steady-state orogenic belts?
- Are there fundamental differences in the topography of active mountain belts between glaciated and non-glaciated terrains? If so, how are these differences manifested in pre-steady-state and steady-state mountains?

To answer these questions, we will combine SRTM topography with cosmogenic nuclide dating, multispectral ASTER imaging, Ikonos DEMs and imagery for select areas, differential GPS, and extensive fieldwork in the Tien Shan. Our previous studies of the topographic growth of even small folds provide insight on progressive dissection of pre-steady-state topography. This proposed research will permit us to extend these studies to the scale of ranges and to illuminate details of both channel networks and hillslopes as they evolve toward steady state in both non-glacial and glacial topography. Although not specifically focused on natural hazards, progressive topographic change defines the template on which surface processes generate hazards. Moreover, quantification of the spatial and temporal evolution of fluvial networks, hillslopes, and topography will permit development of new models for the growing collisional mountain belts and will provide insights on the tectonic, climatic, and erosional controls on their topographic evolution.

Burbank
American Chemical Society
41960-AC8 BDI02
Illuminating the evolution of thrust-fault systems using deformed geomorphic markers
01/01/05-08/31/07
$79,658.59

Burbank
National Science Foundation
EAR-0408675 BDN06
Collaborative Research: Reconciling geologic and geodetic rates of deformation: The role of distributed strain in the upper crust
07/01/04-06/30/07
$47,980
Displacement rates on faults, both past and present, are the observational foundation for understanding the geodynamics of rapidly deforming lithosphere. In principle, knowledge of the spatial and temporal distribution of surface deformation rates can yield insights into rupture behavior, lithospheric rheology, and slip transfer along networks of faults. At present, two primary data sets define these rates: geodetic data (primarily GPS) and geologic estimates of fault displacement. Interpretation of geodetic data is typically accomplished by specifying fault geometries in block models, which relate secular velocity gradients to slip on major faults (e.g., McClusky et al., 2001). Such models rely on two primary assumptions: 1) deformation in block interiors is attributed entirely to elastic strain accumulation on bounding fault zones, and 2) strain accumulation on faults can be modeled as creep on the projection of fault planes beneath an elastic halfspace. Over geologic timescales, of course, the Earth's interior deforms by ductile flow. Models which consider lithospheric deformation as an elastic layer overlying a viscoelastic lower crust and mantle yield an important result: if the Maxwell time is significantly shorter than the recurrence time of characteristic seismic events, then velocities measured in the wake of a recent earthquake are significantly faster than for a corresponding elastic model (REF). Thus, 'discrepancies' between geodetic and geologic data may yield insight into lithospheric rheology (e.g., Dixon et al., 2003), provided, of course, that the rates and distribution of geologic slip are well known.

A striking aspect of the presently available geodetic and geologic data sets in southern and eastern California is the pronounced mismatch that exists along several regional fault systems within the Eastern California Shear Zone (ECSZ), a network of transtensional structures in the western Basin and Range (e.g., Reheis and Sawyer, 1997) and strike-slip faults in the Mojave Desert (Dokka and Travis, 1990). Geodetic studies indicate that ~12-14 mm/yr of right-lateral shear passes through eastern California and must be accommodated, at least in part, by displacement on these faults (Sauber et al., 1994; Savage and Lisowski, 1995; Dixon et al., 1995; Dixon et al., 2000; Miller et al., 2001; McClusky et al., 2001). However, geologic investigations consistently yield slip rates, which total just about 50% of the geodetic velocities (e.g., Beanland and Clark, 1995; Reheis and Sawyer, 1997; Lee et al., 2001). The reasons for this discrepancy are currently unknown: 1) are the fault representations in the geodetic models too simplified to capture the actual displacement patterns; 2) are earthquakes clustered in time, thereby causing highly irregular short-term rates (e.g., Rockwell et al., 2000); 3) does viscoelastic deformation from recent earthquakes 'contaminate' the geodetic data (e.g., Dixon et al., 2003); or 4) are geologic studies missing a significant component of deformation, perhaps distributed on networks of small faults? A satisfactory understanding of strain fields, predicted slip distributions from geodetic data, and interacting fault systems will probably only be achieved once these questions have been addressed.

The scope of the shear zone in eastern California and the numerous structures involved pose a challenge to adequately. Instead, we suggest that critical insights may be gained by examining a relatively restricted region where there is pronounced disagreement between presently understood geodetic and geologic measures of displacement rate, where the fault geometry is relatively simple (but more complex than existing models), and where the opportunity exists to obtain geologic strain rates across an entire fault system.

For these reasons, we propose to conduct a focused study in the northern Owens Valley (Fig. 1). This region contains several major faults (including the Owens Valley fault, White Mountain fault zone, and Sierra Nevada frontal fault system) and numerous smaller faults distributed throughout the valley. Modeling of geodetic campaign measurements suggests that ~6mm/yr of dextral shear passes through the region. Slip rates derived from trenches in the southern Owens Valley (Lee et al., 2001; Bacon et al., 2003) and piercing points in the northern Owens and White Mountain fault systems (Kirby et al., 2002), however, are typically <2 mm/yr or even <1 mm/yr. Dixon and others (2003) recently argued that the geodetic data could be interpreted as a viscoelastic response to the 1872 earthquake on the Owens Valley fault (Beanland and Clark, 1994). However, this result implicitly assumes that geologic slip rates on the Owens Valley fault zone adequately represent the distribution of geologic slip across the entire Owens Valley. The presence of numerous fault scarps, many of which displace Quaternary alluvium, distributed across the valley and into the surrounding mountain ranges suggest to us that a significant component of regional transtension may be accommodated on 'diffuse' fault arrays.

We propose to test this hypothesis by developing budgets for Late Quaternary deformation across the central and northern Owens Valley. Through a combination of tectonic geomorphology, structural geology, and chronology of Quaternary deposits, we seek to understand the distribution of deformation across the valley, as well as the manner in which displacement is passed among structures in this geometrically complicated region. Our goals are i) to provide a more complete description of geologic slip rates and off-fault deformation in the Owens Valley; ii) to test and improve current fault models for the distribution of slip across this zone; iii) to ultimately assess the degree to which discrepancies between geodetic and geologic slip rates reflect the dynamics of temporal variations deformation.

Geologic Setting and Description of Key Questions

Since the pioneering geodetic surveys of Savage and others in the Owens Valley (Savage et al., 1975; Savage and Lisowski, 1980), it has been recognized that a significant component of plate boundary deformation occurs within a ~100 – 150km wide shear zone which trends from the Gulf of California, extends through the Mojave Desert, and passes along the western margin of the Basin and Range province (Savage et al., 1990; Dokka and Travis, 1990; Sauber et al., 1994). Recent geodetic surveys coupled with elastic block models indicate that, at present, ~11-14 mm/yr of right-lateral shear is accommodated within the ECSZ (McClusky et al., 2001; Miller et al., 2001).

South of the Garlock fault, this shear is accommodated on a series of right-lateral strike slip faults in the western Mojave (Dokka and Travis, 1990) and by block rotation in the eastern Mojave (Schermer et al., 1996). North of the Garlock fault, shear is accommodated primarily on 3 regional fault zones: the Owens Lake/Little Lake/Airport Lake systems, the Panamint Valley/Searles Valley/Ash Hill system, and the Death Valley fault zone (Fig. 1). In total, geologic slip rates across these structures appears to be between 5 and 8 mm/yr, or ~50% of the geodetically measured deformation across the ECSZ. This observation seems to be a robust feature of the ECSZ both north and south of the Garlock fault. Recent studies have advanced the hypothesis that this discrepancy reflects dynamic, transient behavior of the fault systems, either as 1) oscillatory strain between conjugate fault systems (Peltzer et al., 2001), 2) a consequence of viscoelastic relaxation following the 1872 Owens Valley earthquake (Dixon et al., 2003), or 3) temporal clustering of seismic strain release (Rockwell et al., 2001). Each of these interpretations carries profound implications for our understanding of the dynamical behavior of fault systems. At present, however, geologic slip rates on some of the key structures in Owens Valley are insufficiently known to fully address the significance of transient phenomena such as these. In particular, we have only a limited understanding of the degree to which strain accommodated on arrays and networks of small, distributed faults within Owens Valley contributes to the total displacement field. In this section, we outline the current state of understanding regarding the geometry and slip rates of major structures in the northern Owens Valley and highlight inadequacies that, in our view, make it difficult to discern, with any degree of confidence, the magnitude of the 'discrepancy' between geologic and geodetic rates.

Burbank
National Science Foundation
EAR-0507431 BDN07
Collaborative Research: Upward and Outward: Tibetan Plateau Growth and Climatic Consequences
09/01/05-08/31/06
$100,384
Intellectual merit:
The Tibetan Plateau not only serves as the world's best laboratory for studying intracontinental deformation, but also acts as the continent's largest perturbation to atmospheric circulation. Accordingly, changes in the height or lateral extent of the plateau both should reflect deep-seated processes in the lithosphere and should affect climate. The proposed research will examine physical mechanisms that link geodynamic processes operating beneath the Tibetan Plateau since Late Miocene time to concurrent local and regional environmental changes. Geodynamic phenomena include folding of oceanic lithosphere south of the Indian subcontinent, the onset of accelerated deformation north of Tibet, and an outward growth of the plateau on its eastern and southeastern margins. Environmental changes include a strengthening of the Indian Monsoon, the aridification of regions both south and northeast of Tibet, and an increase in eolian deposition northeast of Tibet, and even to the North Pacific Ocean. Mechanisms that can link the geodynamic and environmental changes include an increase in the mean elevation of the plateau and an outward growth of it by flow of lower crust that rapidly expands the area of high topography. Much of the plateau has been examined through multi-disciplinary studies supported by the NSF's Continental Dynamics Program, but a key area for understanding the links between these processes, Tibet's northeast margin, remains only cursorily studied. The proposed research will include focused studies (1) to determine when deformation occurred along the northeastern margin of Tibet and how much crustal shortening has occurred, (2) to date the initiation of erosion and river incision into high terrain and (3) to decipher when particular regions of high terrain began shedding debris to both nearby and distant basins, both of which will address when relief was created, (4) to map spatial and temporal patterns of environmental change, (5) to exploit geophysical data to discriminate among possible processes occurring within the crust and mantle, and (6) to understand how high topography affects

regional atmospheric circulation, dust transport, and heat transport within the atmosphere. These studies will create an image of how northeastern Tibet has grown outward and how that growth has affected regional climate.

Broader Impacts:

The interaction between tectonics (large-scale deformation of Earth's crust and upper mantle) and environmental change (especially climate) is emerging at the forefront of the earth sciences. Because of Tibet's role in both large-scale tectonics and as a perturbation to atmospheric circulation and climate, a knowledge of its history of growth and its impact on climate change contributes not only to the understanding of how crust and mantle interact in large-scale continental geodynamics, but also to modern atmospheric sciences through the forcing of climate by topography. This work will bring together young scientists, who constitute the majority of the principal investigators, in a multidisciplinary study that includes sedimentary and structural geology, geochronology and geochemistry, paleoenvironmental study, solid-earth geophysics, and atmospheric sciences. The forefront of modern science lies at the intersections of different disciplines, and graduate and undergraduate students will participate in this interaction first-hand. To demonstrate how such interactions occur and how multiple hypotheses can be addressed and discussed, a short (~15 minute) video aimed at high school students will be created. Finally, by close collaboration with Chinese geologists, this project will foster international collaboration, and with its graduate students and a majority of young principal investigators, this project will encourage the growth of interdisciplinary science.

Burbank
UC Lawrence Livermore National Laboratory
SB050041 BDS02
Calibrating Erosion Rates in Rapidly Eroding Landscapes Using Cosmogenic Nuclides and Numerical Models
08/01/04-07/31/06
$35,704
This proposal aims to develop a collaboration among the Center for Accelerator Mass Spectrometry (CAMS) at LLNL and three departments and one research institute at UCSB. The collaboration will meld existing expertise and facilities at CAMS with numerical modeling, field expertise, and laboratory development at UCSB and will explore ways in which accelerator mass spectrometry can be applied to landscape development and in which landscape models can be applied to problems of interest to LLNL geochemists and climate modelers. The overall goals are two-fold: (i) to develop numerical models and test them with new field data in order to calibrate erosion rates in rapidly eroding terrain using cosmogenic radionuclides (CRNs); and (ii) to initiate the development of a CRN processing/preparation laboratory at UCSB. This lab and the involved faculty are expected to form the basis of a long-term collaboration between UCSB and LLNL in scientific projects related to landscape evolution and global change. LLNL scientist R. Finkel will act as a skilled advisor in planning and setting up the laboratory. Burbank, Dunne, Chadwick, and Niemi each are conducting research focused on erosion rates in mountainous terrains, where they utilize concentrations of cosmogenic radionuclides (CRNs) in sediments to measure erosion rates. In rapidly eroding mountains where landslides dominate erosional flux, traditional methods of assessing erosion rates with CRNs fail to compensate for stochastic variability in the sediment-delivery process due to landsliding. To investigate the impact of landslides and create an appropriate interpretive model and methodology, UCSB research scientist N. Niemi, along with Burbank, Dunne, and Chadwick, is developing a numerical model that uses a calibrated landslide “rule” to predict

the temporal and spatial variability in landslide-induced sediment fluxes and CRNs. The support requested here will help further development of this model and enable model testing and calibration using measured CRN concentrations in key field samples. The result will be an exportable, calibrated model that will have widespread applicability to rapidly eroding ranges around the world. This collaboration will allow UCSB researchers to visit LLNL to learn about sample preparation and analytical techniques employed at LLNL, to assist in AMS runs, and to introduce new interpretive methods to members of CAMS and the Geochemistry Group at LLNL. In addition it will allow Finkel to make several trips to UCSB to learn more about erosion modeling, to aid in setting up a CRN preparation laboratory, and to interact with students interested in applying AMS techniques in their research.

Burbank
National Geographic Society
8135-06 BDP01
Orogeny and Climate: Spatial Patterns of Differential Erosion, South Island, New Zealand
02/15/07-01/01/08
$24,253
An orogen's geometric form is the result of the competition and balance between tectonic uplift and climatically induced erosion. We propose here to use present-day orogenic geometry and measured erosion rates from the Southern Alps and Fiordland ranges of New Zealand to interpret the tectonic and climatic forces driving landscape evolution. By comparing the Southern Alps and Fiordland, we aim to place tighter constraints on how climate interacts with the varying tectonic regimes to control orogenic evolution. Despite their proximity and the similarity of their climate and climatic history, Fiordland and the Southern Alps are characterized by contrasting tectonic geometries and long-term erosion rates that vary by 5- to 10-fold between them. These climatic and tectonic factors, which drive orogenic evolution, have led to marked differences in topographic geometry and patterns of differential erosion. We want to understand why these topographic differences occur, how late Quaternary erosion rates vary spatially within each orogen, how snow-line gradients affect topography and erosional patterns, and whether nascent underplating or continued lateral advection characterizes the underlying tectonics. Overall, this proposal will focus on ways in which interactions between climate and different tectonic regimes influence spatial patterns of erosion and drive landscape evolution. The spatial proximity and climatic similarities between the Southern Alps and Fiordland, contrasted by the dramatic differences in tectonic geometry and erosion rates provide a geographically unique opportunity for a comparative study of the two ranges.

Burbank
National Science Foundation
0510329 BDN08
Collaborative Research: Cosmogenic 3He Dating of Accesory Minerals
08/01/06-07/31/08
$26,385
Intellectual Merit:

The last few years have seen an impressive blossoming of techniques and applications of terrestrial surface exposure dating using cosmogenic nuclides. This new dating has underpinned key advances in the quantification of active tectonic deformation, of geomorphic process rates, and of terrestrial climate change during the Quaternary. Rocky geomorphic surfaces, such as glacial moraines, faulted alluvial fans, and fluvial terraces, have traditionally been difficult to date, especially when their ages exceeded the range of radiocarbon dating. Yet, ages for such features are critical for understanding the timing and rates of tectonic, climatic, and surface processes. Over the past decade, the application of cosmogenic nuclide dating techniques to such features has successfully revealed their geomorphic age and provided a critical chronologic context for interpretations of environmental and tectonic change. Of the handful of measurable cosmogenic isotopes, 10Be, 26Al, and 36Cl have been by far the most widely exploited. Many different minerals can be dated using these isotopes, but the measurements are expensive and require time-consuming chemical purification of large samples, as well as analysis at a highly specialized accelerator mass spectrometry facility. These factors serve to restrict the rate at which ages can be obtained and limit the total number of analyses that can be applied to a given project. In contrast, the cosmogenic noble gas 3He can be measured quickly and inexpensively on small samples of easily obtained mineral separates using mass spectrometers found in many laboratories around the world. However, most common minerals have high non-cosmogenic background levels of 3He and/or they diffuse helium under earth surface conditions.

The purpose of this proposal is to determine whether routine 3He-based surface exposure ages can be obtained on the trace accessory phases: apatite, sphene, and especially zircon. The main advantages of dating these phases with 3He would be low cost, minimal chemical purification, and rapid analyses. These three mineral phases will be considered together because they are purified by the same techniques (usually simultaneously) and more importantly they present precisely the same analytical challenges. As proof of concept, preliminary surface exposure ages based on 3He measurements of zircon and sphene are presented that agree reasonably well with independent constraints. The proposed work consists of two well-focused tasks. The first task is to develop the techniques for routine analysis of cosmogenic 3He in accessory minerals. Very high 4He abundances in these phases will present a major challenge. This work will be on separates from large granitic boulders from previously dated glacial moraines in the Sierra Nevada. These moraines are ideal because they have known exposure ages and because the boulders yield abundant apatite, sphene, and zircon with 3He and 4He concentrations that are typical of the samples which one might ultimately want to exposure date. In addition, to assess the non-cosmogenic component of 3He in these minerals, samples will be analyzed of accessory phases from deeply shielded Sierra granites obtained from water tunnels. For the second task, 3He will be measured in accessory phases separated from rocks from Nepal for which cosmogenic 10Be data are already available. The ultimate outcome of this task should be a plot of 3He concentration in a specific mineral phase vs. 10Be concentration. If the proposed technique is successful, these two isotopes will correlate, and the slope will yield the 3He/10Be production rate ratio. This then provides a first-order production rate estimate for 3He in each phase. As with any attempt to develop a new analytical method there is some risk of failure, a chance that technical challenges will prove insurmountable. In the present case, the preliminary data presented here and the fairly modest cost of the proposal, coupled with the potentially large payoff, warrant the proposed study.

Broader Impacts:

Although the advent of cosmogenic exposure-age dating has underpinned a new era of temporal quantification of tectonic and climatic events and geomorphic processes, high costs and time-consuming analyses lead to routine under sampling. If successful, the new cosmogenic approach proposed here could revolutionize the application of cosmogenic dating. Rather than a handful of samples, dozens of samples could be rapidly and inexpensively dated on any given feature. Powerful insights would undoubtedly be gained from such thorough dating. If proved feasible through the work proposed here, the availability of this new cosmogenic technique would have a profound impact on the design and interpretation of many studies of the chronology of Earth surface changes. 0511053

Busby
Department of Interior
06HQAG0061 BCU03
Spatial Variation in Structural Styles along the Central Sierra Nevadan Range Front: Clues from Segments with Neogene Volcanic Stratigraphy
04/01/06-3/31/07
$11,183.00
I propose a new structural model for the range-front faults of the central Sierra Nevada, and request EDMAP 2006 funds for my PhD student, Jeanette Hagan, to test this model by mapping key transects between Lake Tahoe and Sonora Pass. The Sierra Nevada lie within a microplate bounded to the west by the San Andreas Fault and to the east by the Walker Lane belt, a complex system of dominantly right-lateral strike slip faults. Geodetic GPS studies indicate that the Walker Lane accommodates ~20-25% of Pacific-North America plate motion (Dixon et al., 2000). Much of the present-day displacement between the Sierra Nevada block and the rest of the Great Basin is being taken up along the western edge of the Walker Lane, in rangefront faults of the Sierra Nevada (Fig. 1; Wakabayashi and Sawyer, 2001; see references in Schwieckert et al., 1999, 2000, 2004). Field data from these range-front faults are notably lacking, however, and very little is known of the long-term history of slip on them. I and my students have spent the past five summers mapping and dating the stratigraphy of Tertiary volcanic and volcaniclastic rocks and subvolcanic intrusions in the Sierra Nevada, using modern volcanological facies analysis (Busby et al., 2004; Garrison, 2004; Garrison et al., in review; DeOreo, 2004; DeOreo et al., in review; Roulett, MS thesis in prep; Roulett et al., in prep; Busby and Hagan, in prep; Rood et al., in prep; Skilling et al, in prep; and about 20 abstracts not cited here for space reasons). This detailed work makes me uniquely qualified to determine the amount and timing of Neogene displacement along the range front faults, using volcanic stratigraphic piercing points. The southern Sierra Nevada range-front fault system is simple and straight (Owens Valley fault zone, Fig. 1), but it becomes more complex in the central Sierra (between Bishop and Lake Tahoe, Fig. 1). There, it has been interpreted to form a “northwest-trending zone of en echelon half-grabens developed in Mesozoic granitic rocks of the Sierra Nevada batholith” (my underlining added; p. 305-306, Schweickert et al., 2004). I request funds for Jeanette Hagan to map two transects across the central Sierran range front where I have determined that mappable and dateable unaltered volcanic strata are present (Fig. 2). These transects were chosen in order to test a model developed in part using the results of her EDMAP 2005 work.

We hypothesize that the range front between Lake Tahoe and Sonora Pass (Fig. 2) shows a transition in structural styles. In our model, style I typifies Jeanette’s EDMAP 2005 area at Carson Pass (Figs. 2, 3), and we propose that it is also typifies the Tahoe basin (Fig. 2). Style I is proposed to be a symmetrical, full graben style, with nearly flat-lying volcanic strata down-dropped between planar, continuous faults (Fig. 3). Style II, in contrast, typified by the Sonora Pass – Ebbetts Pass areas (Figs. 2, 4, 5), is proposed to consist of half grabens that step down from the Sierran crest, with west-dipping volcanic strata tilted about west-dipping listric normal faults. On EDMAP 2006 funds, Jeanette will map and date strata and faults of proposed style II in two transects (Fig. 2), in order to compare and contrast them with those of our proposed style I. Our preliminary mapping results also suggest that Tertiary paleocanyons cross the range-front faults without being offset substantially in a strike slip sense.

This suggests that regional focal plane mechanisms may not reflect the long-term strain, but more mapping is needed to test this hypothesis. Jeanette is a PhD student who was named runner-up for a prestigious NSF graduate fellowship earlier this year. She is highly deserving of this support, which will form the basis of her dissertation

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Clark
University of Alaska, Fairbanks
UAF-05-0140 CJG02
Survival of Methane in Rising Marine Bubble Plumes: Testing a Critical Assumption of the Clathrate Gun Hypothesis
03/01/05-02/28/08
$85,977
Marine sediments contain some of the world's largest reservoirs of methane, one of the most important greenhouse gases. These reservoirs include shallow gas hydrates that have both biogenic and thermogenic sources (Kvenvolden, 1993; 1995; Sassen et al., 1999; Buffett, 2000) and deeper hydrocarbon accumulations. Understanding the geological occurrence, geographical distribution, stability, and importance within the global carbon budget of gas hydrates has become the focus of many research initiatives and is a target objective of NURP. Because the global carbon cycle is an integral part of the global climate system, massive dissolution of gas hydrate deposits has been invoked to explain rapid climatic transitions that appear in the geologic record (Dickens et al., 1995; Katz et al., 1999; Kennett et al., 2000, 2003). This idea is commonly referred to as the Clathrate Gun Hypothesis.

Whether or not massive eruptions of gas hydrates can inject enough methane into the atmosphere to significantly warm the planet is controversial for a number of reasons including uncertainties associated with the transport process through the ocean. The Clathrate Gun Hypothesis assumes that the ocean is a passive system unable to take up, store, and oxidize the methane released at the seafloor. During the eruptions, the released methane must travel from the sediments to the ocean surface in large bubble plumes. Because the ocean contains very little methane, there is the potential for a significant fraction of the released methane to dissolve into the water column during its transit.

We propose to examine the dynamics of large bubble plumes in the marine environment to determine the fundamental controls governing the dissolution of rising methane bubbles. We will conduct our research with the Coal Oil Point hydrocarbon seep field, a natural laboratory for studying large bubble plumes in the shallow ocean. The total gas flux to the atmosphere from this field is about 150,000 m3 day-1 (Hornafius et al., 1999) and individual seeps emit as much as 7000 m3 day-1. Measurements collected at the sea surface and throughout the water column at one seep have demonstrated that large bubble plumes modify ocean chemistry and circulation (Leifer et al., 2000; Clark et al., 2003). These plumes create distinct columns of rising seawater and bubbles within the ambient ocean. Our hypothesis is that bubble plume processes enhance the amount of methane that survives the transit through the water column and, thus, the Clathrate Gun Hypothesis assumption that the ocean is unable to take up and oxidize methane released at the seafloor during catastrophic events is valid. This research will examine the potential exchange of seawater between the rising bubble plume and the ambient ocean, a fundamental process that may increase the amount of methane that dissolves into the ocean during its transit through the water column. Earlier research on large marine bubble plumes has neglected to examine this process. Results from this research will compliment fields in addition to hydrate research such as the identification of seafloor vents of oil slicks from either anthropogenic (pipe line leaks) or natural origins.

Clark
Water District of Southern California
SB020079 CJS05
San Gabriel Spreading Area Tracer Study and Rio Hondo-South Montebello Well#5 Tracer Study
01/01/02-12/31/06
$116,914

Clark
National Science Foundation
OCE-0550203 CJN01
Collaborative Research: A three-dimensional, subseafloor, IODP observatory network in the northeastern Pacific Ocean, and initiation of large-scale, cross-hole experiments
02/01/06-01/31/08
$89,100
Intellectual Merit:

This is a proposal for support of multidisciplinary borehole experiments in oceanic crust, to assess hydrogeologic, solute transport, and microbiological processes and properties at multiple spatial (lateral and with depth) and temporal (seconds to years) scales. This work will profoundly improve our understanding of fluid processes within oceanic crust, and will develop new tools and methods that can be applied in many settings. The project includes engineering design and testing, system construction, and observatory servicing, and will support long-term experiments initiated during drilling and by ROV/HOV. These tests and observatories will elucidate and quantify the depth extent of active fluid circulation on a ridge flank, the magnitude of vertical pressure gradients, the importance of hydrogeologic anisotropy, hydrogeologic connections across distances of meters to kilometers, particle transport rates, and relations between lithologic, alteration, microbiological, geochemical, geophysical, and hydrogeologic properties and processes. This work will address numerous hydrogeologic questions, and will generate technologies and techniques important to parts of numerous planned and pending drilling and observatory experiments. Experiments will be run using a network of six subseafloor observatories on the eastern flank of the Juan de Fuca Ridge. This is an ideal place for this work based on earlier drilling experience, available infrastructure, extensive site surveys, and a broad understanding of crustal properties and fluid flow patterns. IODP Expedition 301 (summer 2004) installed three new observatories. A second drilling expedition is to be scheduled in 2008/(07). This NSF proposal is for: CORK and scientific system design and testing; construction of drillship, seafloor, subseafloor, and ROV/HOV instrumentation; emplacement, recovery and replacement of long-term instruments; collection of data and samples from these systems; analysis of data and samples; training of students; and presentation and publication of results. During the next drilling expedition, an existing borehole observatory will be replaced, and two new observatories will be installed, all monitoring multiple crustal levels. Observatories will include the latest generations of pressure instrumentation, continuous fluid sampling systems, microbial colonization substrate, and autonomous temperature logging instruments within the sealed holes. We will run a 24-hour fluid injection experiment in one borehole during drilling and monitor formation response in five other holes 35 m - 2400 m away. We will inject a mixture of tracers to be used in single-hole and cross-hole transport studies. After one-two years of borehole equilibration following drilling, we will use the natural formation overpressure to run a free-flow aquifer test for 1-2 years, allowing us to quantify crustal hydrogeologic properties at enormous spatial scales, and to sample formation fluids and microbes.

Broader Impacts:

Subseafloor observatories comprise a critical part of the Initial Science Plan for IODP, and are included in a large fraction of active proposals being considered by the Scientific Advisory Structure. Subseafloor observatories are also an essential part of the Ocean Observatory Initiative. The work proposed herein will facilitate a new wave of scientific discovery using ocean drilling, subseafloor observatories, and experimental techniques. Individual institutional budgets include considerable graduate student and undergraduate student researcher support, and will help to train a new generation of earth and ocean scientists. Aspects of large-scale fluid flow in the crust have attracted considerable attention in widely-read scientific journals and in the popular press during the last few years. This is high-profile science of broad interest to numerous scientific disciplines and to the public at large.

Dykstra
Meiburg
University of Aberdeen
SB060035 DMP01
UCSB Subcontract for "Stratigraphic development of large scale turbidite slope systems: rules for reservoir modeling and reservoir distribution".
05/01/05-04/30/08
$265,888
The primary objective of the research is to examine a number of slope systems to develop 'rules' that can be used to predict reservoir properties. These rules will be generated through observation, parameter correlation and verification using a family of deterministic outcrop and seismic datasets, and cross-tested against the various datasets. The intention is that they take the form of generic rules that can be exported to different systems with appropriate input changes.

Gans
National Science Foundation
EAR-0230439 GPN01
Neogene Evolution of the Sonoral Margin: The Transition from Backarc Extension
01/01/03-12/31/07
$360,347
Many of the fundamental processes that govern continental rifting and lead to rupturing of continental lithosphere and birth of an ocean remain poorly understood. The transtensional Gulf of California - Salton Trough represents a superb natural laboratory to explore these issues. It provides along-strike and across-strike views of the rifting process and records the transition from distributed continental extension in a backarc setting to final rupturing of the North American lithosphere and capture of Baja California by the Pacific Plate along the modern transform margin. Though much progress has been made in understanding the plate tectonic framework and modern strain field of this region, how this continental rift system evolved <u>in space and time</u> is still poorly understood. Our limited knowledge of how extensional and transcurrent strains are spatially and temporally distributed on the adjacent continental margins - particularly the Sonoran Margin, has made it difficult to adequately evaluate and test models for the kinematic and dynamic evolution of this rift.

This proposal requests funds to quantify the distribution, magnitude, timing, and style of Neogene deformation and magmatism across a portion of the Sonoran rifted margin in order to evaluate the kinematics of the transition from earlier (pre-12 Ma) distributed backarc extension to post-12 Ma transtensional deformation associated with the cessation of subduction and transfer of Baja California to the Pacific Plate. This is an ambitious multi-disciplinary study that will bring together scientists and students from the U.S. and Mexico in an attempt to unravel the history of extension and strike-slip faulting within a particularly well exposed but poorly understood rifted continental margin adjacent to the Gulf of California.

The principal tool to be employed is geologic mapping, as this is the only way to identify the important fault systems and to work out the details of local structural, volcanic, and sedimentary histories. Six investigators (3 senior personnel and 3 Ph.D. students) will devote up to two months/year in the field over a three year period with the goal of deciphering in detail the structural evolution of an 80 by 100 km area in southwestern Sonora, from the coast near Guaymas to the Sierra Mazatan metamorphic core east of Hermosillo. In addition, structural and stratigraphic studies will be carried out on two representative Neogene basins in eastern Sonora to assess whether significant late Miocene deformation affected areas further inboard. Approximately 60 new high-precision $^{40}Ar/^{39}Ar$ age determinations on key pre-, syn-, and post-tectonic volcanic units will be obtained to document local volcanic and sedimentation histories and to bracket the timing of structural events. K-feldspar $^{40}Ar/^{39}Ar$ multi-domain diffusion, apatite (U-Th)/He, and fission track analyses will be employed to determine low temperature cooling histories in the footwalls of large normal fault systems to assess extensional slip histories and to gain insight into erosion rates and thermal structure of the upper crust in the past. This evolving structural, stratigraphic, and geochronologic database will be compiled and continuously updated in a GIS format and made available to the geologic community via the web. Some of the important questions to be addressed by our study include:

·How is strain distributed across the Sonora rifted margin? What are the magnitudes of extension and transform motions across this margin (a) prior to the cessation of subduction at this latitude (pre 12 Ma), (b) during early (12-6 Ma) transtensional deformation, and (c) after final rupturing of the lithosphere and opening of the Gulf of California (post 6 Ma).

·Do the observed strains magnitudes and strain histories on the Sonoran margin support the kinematic model of *Stock and Hodges* (1989), wherein Pacific-North America plate motions were initially partitioned between orthogonal extension inboard of Baja and strike slip deformation outboard of Baja California during "Proto-Gulf" transtensional deformation? Or do the observed strain histories on the Sonora margin suggest an earlier or more gradual transfer of Baja California to the Pacific Plate?

·Was the earlier backarc and intra-arc extension (e.g. *Gans*, 1997) continuous in space and time with younger (post 12 Ma) deformation associated with the change to a transform margin? What influence did the older extensional deformation have on the geometry and kinematics of the younger extensional and/or strike-slip deformation and are their fundamental differences in structural style and strain rate between the deformations that occurred in these two fundamentally different tectonic settings?

·Where was the locus of volcanism during the Neogene evolution of the Sonoran margin and how did its character change as the plate margin evolved from convergent to transform? What is the spatial and temporal relationship between Neogene magmatic activity and deformation?

·What was the character and timing of Neogene sedimentation on the Sonoran rifted margin (as recorded by widespread lacustrine and alluvial fan deposits) and how does this sedimentation relate to the structural evolution?

·Fundamentally, how does the deformational history of the Sonoran rifted margin relate to the geometry and kinematics of the evolving North America-Pacific plate boundary and what does this imply about the relative importance of plate boundary versus body forces as a driving mechanism for distributed continental deformation?

The greatly improved understanding of the Neogene pre-rupturing history of the Gulf of California region that will emerge as a direct consequence of our investigation of the Sonoran margin will place critical new constraints on models for the evolution of this continental rift.

Gans
Rio Tinto Exploration
SB060013 GPP02
Miocene stratigraphy of the Gravel Hills-Mud Hills-northern Calicvo Mts., central Mojave Desert, CA
09/01/05-12/31/06
$6,048
Funds are requested to partially support an integrated field and geochronologic investigation of the sedimentation and tectonic history of the central Mojave aimed at reconstructing the stratigraphic architecture and structural deformation of the Miocene sedimentary basins north of the latitude of Barstow. This study will constitute the Ph.D. thesis for **Error! Contact not defined.**, under the direction of Dr. Phil Gans at UCSB. The study will include:

1) Detailed geologic mapping at a scale of 1:12,000 of critical regions in the central Mojave comprising a 70 km along-strike and 60 km across-strike transect of exposed Miocene sedimentary rocks.
2) Compilation of accurate stratigraphic sections from isolated ranges and reconstruction of the 3-dimensional stratigraphic architecture of the Miocene basin illustrating variations in the character and thickness of different lithologic units.
3) Stratigraphic analysis of paleocurrent and provenance data, and reconstruction of the paleogeography of the central Mojave.
4) Compilation of an extensive $^{40}Ar/^{39}Ar$ geochronologic database of sedimentary rocks across the region and construction of a temporal framework in which to place the stratigraphic architecture of the basin and evaluate the timing and distribution of lithofacies in time.
5) Final synthesis including a series of "time slices" maps illustrating relations between the tectonic history and the sedimentation of the region in time.

This evolving database will be made continuously available to Rio Tinto personnel for the duration of the research and copies of the final dissertation and any supplementary data will be provided to interested parties upon completion of the study in June of 2007.

Hacker
National Science Foundation
EAR-0215641 HBN07
Collaborative Research: Thermal, Petrological, and Seismological Study of Subduction Zones
09/01/02-08/31/06
$130,126
We propose to continue our thermal–petrological–seismological study of subduction zones to attack some significant new issues:

1) The geometry and vigor of mantle-wedge convection represent a major source of uncertainty in modeling the thermal structure of subduction zones. To better understand the extent of hydration and the relationship between forearc mantle hydration and the depth of slab–wedge viscous coupling, we propose to ...
2) Expanding our phase diagrams—and hence automated rock properties calculations to metasomatized MORB will address how the variability of oceanic crust affects physical properties, dehydration, and, potentially, seismicity. We will incorporate the effects of fluid or melt-filled cracks or other porosity into our calculations, and deliver this improved mineral and rock properties spreadsheet to the community.
3) Further tests of the dehydration–seismicity hypothesis will be made by examining the petrological structure–seismicity patterns in more subduction zones—especially those with PT paths intermediate between the “hot” and “cold” endmembers—and by evaluating whether along-trench changes in seismicity along individual subduction zones vary in ways consistent with the dehydration–seismicity hypothesis. We will also determine whether peaks in seismicity and moment rate correlate better with areas of predicted dehydration or to changes in slab shape.
4) Testing the hypothesis that lower seismic zones are permitted by mantle dehydration...
5) Using full-waveform modeling coupled with the petrologic modeling, we will test a suite of realistic slab models against the observed dispersion curves.
6) Earthquake hypocenters provide key tests of the double seismic zone hypothesis, the hypothesis that the main zone is associated with hydrated mafic rock, and the notion that the forearc mantle wedge is aseismic. Specifically, it would be valuable to place constraints on the maximum/minimum possible width of a double seismic zone, on locations of dip changes, and to quantify the likelihood of any possible events lying within the mantle wedge.

Hacker
National Science Foundation
EAR-0003568 HBN06
Collaborative Research: United States-China Scientific Cooperative Project
08/01/01-07/31/06
$276,114
The Sulu ultrahigh-pressure (UHP) metamorphic terrane in east-central China is part of the Sulu-Dabie-Hong’an-Qinling suture between the Sino-Korean and Yangtze cratons. Together the Sulu, Dabie and Hong’an terranes constitute the world's most extensive exposures of UHP rocks and have been identified as the primary Chinese research target for the next five years. We propose a multidisciplinary investigation of the Sulu UHP terrane in conjunction with the Chinese Continental Scientific Drilling Program (CCSD). Our objective is to understand the mechanisms and processes by which buoyant continental crust is subducted to depths exceeding 100 km and then exhumed, and to quantify the relationships of this process to continental collision. Reflection seismic profiling, structural geology, rare-earth-element geochemistry, geochronology, stable- and radiogenic isotope geochemistry, petrology and mineralogy—of surface rocks and core samples from the CCSD project—will be employed to test existing geodynamic hypotheses. We plan to build on our 10-year geochronological-petrological-structural study of the Dabie-Hong’an area by completing a parallel study in the Sulu region. Validated models of UHP tectonics and continental collision will be built upon the foundations provided by this and previous work.

It is an accepted tenet of geology that very low T at high P constitutes a “forbidden zone” never realized in the Earth— all exposed rocks appear to have experienced geothermal gradients hotter than 5–10°C/km. In the Sulu-Dabie terrane, however, we have recently discovered ultramafic rocks from the forbidden zone. These rocks must have formed in a cold subduction zone and constitute important recyclers of H2O into the mantle. Recent UHP experiments reveal that numerous hydrous phases are stable in the forbidden zone; some occur in the Chinese UHP rocks. Garnet peridotites with an upper mantle signature are rather abundant in the Sulu region and are a major target of the CCSD project. They provide not only a wealth of information on the physical and chemical characteristics of the lithospheric mantle, but also provide valuable insight into the dynamics of crust/mantle interaction during continental subduction, during collisional orogenesis, and within the forbidden zone.

The key questions we expect to answer are:

(1) What crust-mantle interaction processes take place when continental material is subducted to great depths, and how do such processes affect crustal growth and global geochemical recycling? Can state-of-the-art analytical tools determine the age of fluid/rock interactions?
(2) What new constraints on petrotectonic processes do UHP garnet peridotites of the mantle wedge provide? How were such peridotites emplaced into the crust during subduction, and how did they evolve during exhumation?
(3) What are the implications of UHP metamorphism at forbidden-zone P-T conditions and what roles do hydrous phases in the cold subducting slab play in the recycling of volatiles into the Earth's mantle?
(4) How do we differentiate the subduction/collisional architecture of orogens from the effects of younger events using present-day deep-seismic profiles?
(5) What exhumation mechanisms and rates of ascent prevent UHP mineral assemblages from being completely obliterated by metamorphic overprinting and/or partial melting?
(6) In what tectonic settings are the generation and exhumation of UHP rocks possible? Is continental collision required?

Our proposed U.S.-China–Japan–France–Germany–UK cooperative project will establish fruitful scientific exchange among international researchers. We will obtain essential seismic, structural, petrochemical, mineralogical, and geochronological data that address the questions enumerated above. It is important that this project begin soon to take advantage of the ICDP Donghai drilling project started in 2000. We have already begun exchanges with our CAGS colleagues, and limited research on core samples recovered from the pre-pilot holes has commenced.

Hacker
National Science Foundation
EAR-0309995 HBN08
Collaborative Research: Direct Observation of Depth Variation in Fault Zone ...
01/15/04-12/31/07
$116,316
Intellectual Merit of the Proposed Activity:

The relationship between earthquake mechanics and fault-zone structure is one of the most fundamental unresolved issues in earthquake science. It remains unclear whether seismic ruptures always occur on a well defined planar structure or whether the complexity observed in exhumed fault zones plays an important role in the nucleation and propagation of earthquakes. Stated another way, is earthquake mechanics fundamentally a problem in granular mechanics, or should it be viewed primarily in terms of frictional sliding along a single slip surface? These issues are critical for the question of scaling laboratory experiments to the natural faulting environment. A related issue is the role of fault-zone structure in the long- and short-term transport of fault-zone fluids, and their role in the faulting process. Although much has been learned about these issues from structural studies of exhumed examples, seismic studies of active fault zones, and laboratory studies of the mechanics of earthquake nucleation, this overall set of issues has proven to be extremely difficult to address in a systematic fashion on a single fault. This proposal seeks to exploit a unique example of a major strike-slip fault that has been tilted during exhumation, such that a continuum of exhumation levels—from the near-surface down into the lower crust—are now exposed along strike. Moreover, this fault (the Miocene Salzach-Ennstal-Mariazell-Puchberg [SEMP] fault zone in Austria) has participated in its own exhumation to a limited extent, reducing potential structural overprints related to younger faulting.

Objectives and methods:

The proposed research will characterize the geometry and internal structural architecture of the SEMP fault zone throughout the entire depth range of the seismogenic crust, with a focus on the recognition of depth-dependent changes in fault-zone structure. Field studies will focus on structural transects across the SEMP fault zone at exhumation levels ranging from the near-surface at the eastern end of the fault (Vienna pull-apart basin), within the seismogenic crust (central Austria), and down into the ductile lower crust exposed in the Tauern window of western Austria. In addition to detailed field mapping of structural fabrics, fluid-rock interactions, relative timing relationships, and variations in fault geometry, the proposed research will include detailed analysis of fault-zone rocks designed to explore deformation at a wide range of scales using petrographic microscopy, cathodoluminescence microscopy, fluid-inclusion studies, scanning electron microscopy, and transmission/analytical electron microscopy.

Broader Impacts:

At least one graduate student and one undergraduate will be actively engaged in the proposed research, which should give them many of the tools they need to be productive researchers. The teaching abilities of the graduate student should improve as a result of interaction with the undergraduate, and through teaching assistantships they will have during the 1-2 years of their PhD studies for which they are not supported by this project. The project will enhance the infrastructure for research at USC and UCSB through the continued use of existing facilities, which always leads to improvement. Research at allied institutions will benefit from the networks and partnerships constructed among the senior researchers and the students (e. g., our active collaboration with Professor Lothar Ratschbacher and his students at the University of Freiberg in Germany). The results of the project will be disseminated through peer-reviewed earth science journals and formal presentations at the GSA and AGU national conventions and joint AGU-EGS-EUG meetings in Europe.

Hacker
National Science Foundation
0632774 HBN09
Support for the Penrose Conference on Arc Crustal Genesis and Evolution
06/15/06-05/31/07
$15,000
This proposal is a request to support participant costs to the Penrose Conference on Arc Crustal Genesis and Evolution will be held in Valdez, in south-central Alaska, from July 9–15. Presentations will integrate recent results on well-exposed arc crustal sections—in the Jurassic Talkeetna arc in south central Alaska, and in the Cretaceous Ladakh–Kohistan arc in northern Pakistan and India—with important new developments in active-arc geochemistry, petrology and geophysics. The Talkeetna and Ladakh–Kohistan arcs provide exposures of relatively complete sections from Moho depth (30 to 40 km in both

cases), to volcanic rocks and volcaniclastic sediments. Both have been the subject of large, multi-disciplinary projects over the past decade, and provide depth sections and temporal progressions that are not accessible in active oceanic arcs. Intensive, recent investigations of arc plutonic suites elsewhere complement these projects. New data from the US MARGINS Initiative, Sierra Nevada Continental Dynamics Projects, Aleutian studies, and similar international initiatives provide constraints on crustal thickness and volcanic fluxes in active arcs. Advances in the study of melt inclusions have dramatically improved understanding of volatiles in primitive arc magmas. Studies of ultra-high pressure metamorphic rocks and new experimental methods have yielded insights into mantle wedge melt generation, and subduction zone dehydration and anatexis. This conference will provide an opportunity to synthesize these results, with a focus on using direct observations of arc crustal sections, from the uppermost mantle to the volcanics, to constrain arc processes and their role in the genesis and evolution of continental crust.

Hacker
Boles
Haymon
Mattinson
Porter
National Science Foundation
0649933 HBN10
Acquisition of a New Electron Imaging Facility
06/01/07-05/31/08
$299,745

Intellectual Merit:

The Earth Science Department at the University of California, Santa Barbara requests partial support to establish a new electron imaging facility with coupled cathodoluminescence, electron-backscatter diffraction, and energy-dispersive analysis systems. This state-of-the-art facility will provide new opportunities and continuing support for a wide range of exciting research by principal investigators, students, and visitors on topics as diverse as: i) new methods in zircon geochronology, ii) new methods of imaging microbes in geologic/environmental samples with genetic probes; iii) the genesis and exhumation of ultrahigh-pressure rocks, iv) the origin and early diversification of life on Earth, v) biomineralization in early animals, vi) mineral-microbe interactions in seafloor hydrothermal systems; vii) the role of clay and quartz crystal orientation in pressure solution, viii) signals of methane influence on foraminifera, and ix) the paleoclimate record in speleothems and tests. Our new progress in these areas will be facilitated by three new capabilities: i) operating at low vacuum, ii) coupled EBSD–EDS analysis, and iii) position-tagged EDS spectrometry. UCSB is providing $90,000 in matching funds, and continuing fulltime salary support for two development engineers to operate, enhance and maintain the facility. The facility will replace aged instruments that underpin much of our ongoing research programs. The core parts of our existing facility exhibit increasingly frequent and more expensive electronic and mechanical component failures that are hindering our research and teaching productivity. As we replace retiring faculty over the next 10 years, the new facility will attract competitive young new scientists and ensure the long-term vitality of geochemistry, geochronology, petrology, structural geology, paleontology, and paleoclimatology research and education at UCSB.

Broader Impacts:

The proposed facility will not only constitute an important infrastructure overhaul, but it will enable several new capabilities: energy-dispersive analysis of light elements, charge contrast imaging, and coupled energy-dispersive—electron-backscatter diffraction analysis. Over the past five years, the existing facility has been used by twelve faculty members inside and outside of UCSB, and by several dozen postdoctoral scholars, graduate students and undergraduate students to produce >100 research publications and more than one dozen theses and dissertations. It is used routinely in teaching half a dozen undergraduate courses at UCSB (GS 2, 14, 102b, 102c, 162) and is one of our showcase instruments we use to reveal the microscopic world during "young scientist" visits from the local K-12 grade schools. This new facility will be the primary research tool for a newly hired female assistant professor.

Hacker
Mattinson
National Science Foundation
20050638 HBN01
The Assembly of UHP Terranes: Was the Western Gneiss Region Built by Sequential or Repeated (Ultra) High-Pressure Events?
07/01/05-06/30/08
$328,178

Intellectual Merit of the Proposed Activity:

Understanding the formation and exhumation of ultrahigh-pressure (UHP) rocks continues to be one of the outstanding tectonic questions of our time because of the impact such processes have had on the exchange of material between the crust and mantle, the generation and collapse of mountain belts, the formation of continental crust, and tectonic plate motions. Research into UHP rocks is still in an exciting phase wherein some of the basic facts about the formation and exhumation of UHP rocks are known, but many first-order questions remain unanswered.

Objectives and Methods:

This proposal is to test whether the Scandinavian UHP orogen formed through repeated subduction of the same tectonic unit or through sequential subduction of different units. The site of study is the Western Gneiss Region of Norway, the best exposed and largest UHP terrane. The techniques to be used are state of the art geochronology and petrology.

The present dataset suggests that the eclogites formed in as many as four stages from 503 Ma to 400 Ma, but there are not enough data to establish any spatial pattern to these ages, nor to even be sure whether the Western Gneiss Region really experienced four distinct (U)HP metamorphic episodes. As a result, one cannot formulate credible models of how and why these remarkable rocks formed. These questions can be answered with a combination of U/Pb zircon and Th/Pb monazite geochronology. The strength of this approach lies in its integration of different chronometers, collaboration with researchers at cutting-edge facilities, and our familiarity with other ultrahigh-pressure orogens. The impact of this research should be considerable because of the archetypal nature of the Norwegian UHP terrane.

Broader Impacts:

At least two graduate students (Scott Johnston, MS Stanford) and Andrew Kylander-Clark, MS UNC) and one undergraduate will be actively engaged in the proposed interdisciplinary (geochronology?petrology?structure) research, which will give them many of the tools they need to be productive researchers. The teaching abilities of the graduate students will improve as a result of interaction with the undergraduate, and through teaching assistantships they will have during the 1?2

years of their PhD studies that they are not supported by this project. The project will enhance the infrastructure for research at UCSB through the continued use of existing facilities, which always leads to improvement. Research at allied institutions in the US and Norway will benefit from the networks and partnerships constructed among the senior researchers and the students. The results of the project will be disseminated through peer-reviewed earth-science journals.

Hacker
National Science Foundation
EAR-0545399 HBN02
Collaborative Research: Earthscope integrated investigation of Cascadia subduction zone tremor, structure and process
01/01/06-12/31/09
$138,744
Intellectual Merit:

We propose an integrated Earthscope field experiment in the Cascadia subduction zone to elucidate the relationship between water transport, aseismic slip, episodic tremor, and arc magmatism. Globally, Cascadia represents an end-member of subduction in that some of the youngest and warmest lithosphere on Earth is being subducted, leading to predictions that the down going plate is dehydrating at unusually shallow depth. Nevertheless, a volcanic arc exists with abundant H2O in some magmas, indicating that there must exist pathways by which H2O travels through the entire subduction system. Our ultimate aim is to explore the processing of H2O in subduction zones using the tools of seismology, geodesy and petrology, and to integrate these results with complementary constraints from geodynamics and geochemistry. Seismic imaging will illuminate the descending oceanic plate where it metamorphoses and illuminate the mantle wedge where fluids may be producing hydrous phases such as serpentine or, beneath the volcanic arc, primary magmas. We design our experiment to traverse the one part of the Cascadia system where earthquakes extend to nearly 100 km depth, so we can investigate the relationship between the release of fluids and the generation of Benioff-zone earthquakes. The transport of fluids may be also a primary driver for episodic tremor and slip (ETS), a phenomenon observed in Cascadia perhaps better than anywhere else on the planet. We will integrate measurements of tremor from known source regions with slip distributions derived from GPS data and existing long-baseline tiltmeters. Together with the proposed seismic imaging, these observations will yield an unparalleled data set for determining the relationship between tremor, slip and the regions where imaging indicates metamorphism of the down-going plate or hydration of the overlying mantle wedge. Project Plan. The basic experiment has four components: a broadband imaging array of flexible-array instruments integrated with Bigfoot, three small-aperture seismic arrays near sources of non-volcanic tremor, analysis of the PBO and PANGA GPS data sets to define the details of episodic slip events, and integrative modeling. The broadband array features a dense transect across the part of the Cascadia subduction system that includes intermediate-depth earthquakes and the Nisqually earthquake hypocenter, in a staggered configuration to allow along-strike effects to be tested. That will be complemented by 2 cross lines, one crossing the slab where the crust appears to be dehydrating, and one in the Cascades foothills to sample the roots of the arc. The tremor and GPS arrays are collocated with the broadband imaging as much as possible, to allow simultaneous location of tremor and slip and imaging of their source region. These data will be subject to the gamut of analyses appropriate to such data, including array analysis for wave-front orientation of tremor waves, migration of teleseismic scattered waves, tomographic images of Vp, Vs and Q, shear wave splitting, earthquake relocation, investigation of high-frequency phases interacting with the slab, and specialized GPS processing designed for the detection and quantification of transient events. The interpretations will be made in conjunction with detailed petrological–thermal models of the Cascadia subduction system. These results will place new constraints on the dehydration pathways within the down-going plate, the relationship between structure and seismicity at intermediate depths, the relationship between transient strain events and structure, the temperature, melt and volatile content of the mantle wedge, and the growth of continental crust.

Broader Impact:

(1) A key part of the Earthscope philosophy is that investigations serve as a springboard for broad-based, multidisciplinary research. We plan to accomplish this through an open workshop, roughly 1 year after deployment ends, to be proposed separately. We commit to some basic data products to be presented at that meeting. In this way, the Earthscope facility acts as a starting point for a wide variety of future work, all of which take advantage of the advance in imaging that the USArray tool provides. (2) The Cascadia subduction zone and the intraslab earthquakes within it form a significant U.S. hazard, which should be better assessed with the results collected here. This proposal is written in partnership with research at the USGS, with the aim of making significant contributions to understanding of Cascadia earthquake hazards.

Ji
Department of Interior
00017896 JCU01
Collaborative Research with University of California Santa Barbara and USGS: Real-time Global Earthequake Characterization
10/1/05-12/31/06
$65,000
The great Sumatra-Andaman island earthquake reminds us of the natural hazards caused by great Earthquakes in a hard way. When such tragedies occur, quick ground shaking estimates are very important to local governments for their earthquake emergency response and earthquake hazard relief efforts. Recent developments in global broadband seismic instrumentation and in inverse methods have made it possible to construct an earthquake slip history based on teleseismic observation. Using the 1999 Chi-Chi and the 2002 Denali earthquakes as examples, we have shown that such a model could be used to predict ground shaking in the near-fault region and provide the basis for evaluating the overall impact of an earthquake [e.g., *Ji et al*., 2004]. During the last two years, we have been developing an automatic system and studied tens of magnitude 7 and larger earthquakes. Some of those results have been implemented in the NEIC posters for large earthquakes. These studies, particularly the 2004 Sumatran-Andaman Island and the 2005 Nias earthquakes, have not only illustrated its importance, but also shown the limitation of current methodology and possible directions for improvement. Considering the potential seismic hazard of the Cascadia region which is geologically comparable to the Sumatran subduction zone, it is important to update the current system by incorporating some of the methods developed during the study of these two events. This proposal asks for support to conduct these improvements at UCSB, in collaboration with Drs. Yuehua Zeng and David Wald for implementation at NEIC.

Ji
Department of Interior
07HQGR0068 JCU02
Collaborative Research with University of California Santa Barbara and USGS
01/01/07-12/31/07

$58,000
This proposal is a continuation of research that was funded by NEHRP in 2005 and started in October 2005.The great Sumatra-Andaman island earthquake reminds us of the natural hazards caused by great earthquakes in a hard way. When such tragedies occur, quick ground shaking estimates are very important to local governments for their earthquake emergency response and earthquake hazard relief efforts. Recent developments in global broadband seismic instrumentation and in inverse methods have made it possible to construct an earthquake slip history based on teleseismic observation. Using the 1999 Chi-Chi and the 2002 Denali earthquakes as examples, we have shown that such a model could be used to predict ground shaking in the near-fault region and provide the basis for evaluating the overall impact of an earthquake [e.g., *Ji, et al*., 2004]. During the last few years, we have been developing an automatic system and studied tens of magnitude 7 and larger earthquakes. Some of those results have been implemented in the NEIC posters for large earthquakes. These studies, particularly the 2004 Sumatran- Andaman Island and the 2005 Nias earthquakes, have not only illustrated its importance, but also shown the limitation of current methodology and possible directions for improvement. Considering the potential seismic hazard of the Cascadia region which is geologically comparable to the Sumatran subduction zone, it is important to update the current system by incorporating some of the methods developed and taking advantage of high performance computing (HPC) technique. This proposal asks for support to conduct these improvements at UCSB, in collaboration with Drs. Yuehua Zeng, Paul Earle, and David Wald for implementation at NEIC.

Keller
Burbank
Department of Interior
07HQGR0040 KEU01
Earthquake Hazard of the Camarillo Fold Belt: The Last Remaining Fold Belt in the Southern California "Hot Spot"
01/01/07-04/30/08
$60,000
The Camarillo fold belt (CFB) in the western Transverse Ranges presents a potentially serious earthquake hazard to millions of people living in southern California, yet it has not been studied as a unit for the purpose of evaluating the seismic hazard. The CFB is the last unstudied fold belt of the “Hot Zone” of active seismicity, identified by the Southern California Earthquake Center, likely to have >4 damaging earthquakes in the next century. Urbanization of the CFB has prompted hundreds of site-specific consulting reports and one site-specific NEHRP project, which have verified the existence of active faults capable of generating an Mw7 earthquake. The abundance of data collected in these consulting reports will allow a regional analysis of the earthquake hazard to be completed at a fraction of the original cost. However, due to rapid urbanization the window of opportunity to study the faults and folds of the CFB is rapidly narrowing. Several active growing folds and oblique-slip reverse faults deform late Pleistocene-Holocene sediments of the Oxnard Plain. Although, contractional deformation likely exceeds 10 mm/yr., no studies have determined the precise rates of slip or recurrence intervals on individual structures. Nor is the tectonic framework and relationship of the CFB to other fold belts to the north, south and west known. This research is designed to synthesize the wealth of consulting reports that exist, quantify the rates and magnitude of deformation across the CFB, determine how strain is partitioned on individual structures, and evaluate the seismic hazard. Research Objectives: To successfully characterize the paleoseismic history of the CFB and evaluate the earthquake hazard, our specific objectives include:

• Identify and map the seismic sources of the CFB.
• Establish the late Pleistocene to Holocene chronology of alluvial deposits.
• Quantify rates and magnitude of deformation.
• Determine the tectonic framework and links to the regional geologic environment.
• Estimate the earthquake hazard.

Research Methods:
• Detailed field mapping of active faults and deformed geomorphic surfaces.
• Tectonic geomorphic analysis of landforms and processes.
• Relative and absolute dating (14C and OSL) of late Pleistocene-Holocene alluvial deposits and geomorphic surfaces.
• Construction of balanced cross-sections to quantify the magnitude of shortening and subsurface geometry of faults. Link the tectonic displacement and chronology of deformation to estimate rates of slip.
• Excavate fault trenches to evaluate paleoseismicity, and evaluate earthquake hazard based on recency of faulting.

Anticipated Results:
• Detailed map of the major seismic sources and deformed geomorphic surfaces.
• Balanced cross sections.
• Add to Quaternary chronology of southern California.
• Illuminate the unknown seismic hazard for this part of southern California
• Model of fold development for the CFB.
• Linked southern California fold belts, illuminating the plate boundary evolution.

Implications for Project Results:
Development of the chronology of Quaternary units in the area along with trenching of faults and folds will greatly increase our understanding of the earthquake hazard of the CFB as well as assist in the development of a regional model to explain development of folds and buried reverse faults during the Pleistocene.

Luyendyk
National Science Foundation
0639006 LB07
Collaborative Research: The 10th International Symposium on Antarctic Earth Science (ISAES X)
04/01/07-03/31/09
$168,293
Contemporary views of Earth as an integrated system assign a critical role to Antarctica, with its profound influences on ocean and atmospheric circulation, Earth albedo, and geodynamics. Antarctica holds a repository of information about Earth climate, global change, and geodynamic transitions of the past 900 million years. The International Symposium on Antarctic Earth Sciences (ISAES) in 2007 will be an integrated, multidisciplinary meeting that brings global scientists together to explore lithosphere, hydrosphere, atmosphere and biosphere linkages under the theme **Antarctica: A Keystone in a Changing World**. Inaugurating the International Polar Year (IPY), the meeting will establish new directions for interdisciplinary Antarctic research in the 21st Century. The ISAES is the foremost international Antarctic geoscience meeting, convened once every ~4 years since 1963. Historically the

focus has been on the lithosphere, attracting ~300 – 400 scientists from up to 35 countries who carry out research in geophysics, geochemistry, and geology. An innovation in 2007 will be to organize the symposium around cross-disciplinary themes that will engage the glaciology, oceanography, and biology communities along with solid Earth scientists. The symposium will feature new and emerging technologies that are changing the scope and pace of scientific discovery on the continent, which stimulate and rely upon ever-closer international cooperation. The ISAES Organizing Committee seeks NSF funding for the 10th ISAES, to be being held in the United States for the first time since 1977. The venue is University of California, Santa Barbara, a leading research university situated along the tectonically active Pacific Rim. By hosting the meeting and formulating a vision for the direction of future research, the U.S. Antarctic Program will have an opportunity to assert a strong leadership role in implementing a broad Earth systems approach to Antarctic science, augmented by emerging technologies. Funds requested from NSF are for science management, travel for keynote speakers, domestic and foreign travel grants, student registration subsidies, and publication costs. Registration fees paid by participants will cover the venue and staffing, and a modest social program. Additional funds come from the Scientific Committee on Antarctic Research, SCAR, and its program on Antarctic Climate Evolution, ACE, and carry-forward from the 9th ISAES. The USGS is supporting a portion of the cost of publication of the symposium proceedings. Scientific workshops and field excursions will be run under a self-supporting financial model.

Intellectual Merit:

The scientific program presents multidisciplinary themes of interest to all Earth scientists, whether or not they engage directly in Antarctic research. Themes include: *Antarctica in the Global Geodynamic System; Antarctic Climate Evolution; GeoCryoDynamics; Antarctic Earth Science in the International Polar Year; Polar Education and Outreach Initiatives; Antarctica's Impact on Global Biosphere Evolution; New Frontiers in Technologies and Polar Databases*. The 10th ISAES will implement an innovative publication model for early submission and peer review prior to the symposium, with combined on-line publication at the meeting and print soon after. Symposium publications are expected to provide a valuable resource for new research carried out during IPY.

Broader Impacts:

The ISAES promotes multidisciplinary research and international collaborations, even between nations with overlapping territorial claims in Antarctica, thereby helping to maintain one of the tenets of the Antarctic Treaty, namely peaceful co-existence and cooperative research endeavors. As an inaugural event for IPY, the Symposium will attract media coverage and raise the public profile of polar science. Moreover, the symposium serves as an entry portal for young researchers just beginning to discover the importance of Antarctic research and strategies for organizing international collaborations. Travel grants for students and individuals involved in emerging programs are consequently of great importance. An innovation for 10th ISAES is to involve glaciology, oceanography, and biology communities along with solid Earth scientists, as a stimulus for new directions of multidisciplinary research and providing avenues for new participation in Antarctic research by developing nations and underrepresented groups.

Luyendyk
National Science Foundation
ANT-0088143 LBN06
Collaborative Research: Antarctic Cretaceous-Cenozoic Climate, Glaciation, and Tectonics: Site Surveys for Drilling from the edge of the Ross Sea Shelf"

09/15/01-02/29/08
$470,720
We propose to conduct sites surveys for drilling from the Ross Ice Shelf into the seafloor beneath it. Many of the outstanding problems concerning the evolution of the East and West Antarctic Ice Sheets, Antarctic climate, global sea level, and the tectonic history of the West Antarctic Rift System will be solved by drilling into the seafloor of the Ross Sea. Climate data for Cretaceous and Early Cenozoic time are lacking for this sector of Antarctica. Climate questions include: Was there any ice in Late retaceous time? What was the Antarctic climate during the Paleocene-Eocene global warming? When was the Cenozoic onset of Antarctic glaciation, when did glaciers reach the coast and when did they advance out onto the margin? Was the Ross Sea shelf non-marine in Late Cretaceous time; when did it become marine? Tectonic questions include: What was the timing of the Cretaceous extension in the Ross Sea rift; where was it located? What is the basement composition and structure? Where are the time and space limits of the effects of Adare Trough spreading? Another drilling objective is to sample and date the sedimentary section bounding the mapped RSU6 unconformity in the Eastern Basin and Central Trough to resolve questions about its age and regional extent. Deep Sea Drilling Project Leg 28 completed sampling at four drill sites in the early 1970's but had low recovery and did not sample the Early Cenozoic. Other drilling has been restricted to the McMurdo Sound area of the western Ross Sea and results can be correlated into the Victoria Land Basin but not eastward across basement highs. Further, Early Cenozoic and Cretaceous rocks have not been sampled.

A new opportunity is developing to drill from the Ross Ice Shelf. This is a successor program to the Cape Roberts Drilling Project. One overriding difficulty is the need for site surveys at drilling locations under the ice shelf. We propose to overcome this in our project proposed here. We request funding to conduct marine geophysical drill site surveys at the front of the Ross Ice Shelf in the Central Trough and Eastern Basin. The surveys will be conducted a kilometer or two north of the ice shelf front. In 2 to 4 years the northward advance of the ice shelf will override the surveyed locations and drilling can begin. Systems to be used include swath bathymetry, gravity and magnetics, chirp sonar, high resolution seismic profiling, and 48 fold seismics. Cores will be collected to obtain samples for geotechnical properties, to study sub-ice shelf modern sedimentary processes, and at locations where deeper section is exposed. Our survey will include long profiles and detailed grids over potential drill sites. Survey lines will be tied to existing geophysical profiles and DSDP 270. One fact that makes this plan timely is the calving of giant iceberg B-15 and others from the ice front in the eastern Ross Sea. This new break away and one in 1987 have exposed 16,000 km^2 of seafloor that has been covered by ice shelf for decades and is not explored. Newly exposed territory can now be mapped by modern geophysical methods. We will be able to map structure and stratigraphy below unconformity RSU6 farther south and east, study the place of Roosevelt Island in the Ross Sea rifting history, and determine subsidence history during Late Cenozoic time (post RSU6) in the far south and east. Finally we will observe present day sedimentary processes beneath the ice shelf in the newly exposed areas.

Mattinson

National Science Foundation
0549672 MJN02
Collaborative Research: Development of Improved Zircon Standards for SIMS and LA-ICP-MS-U-Pb Geochronology using CAT-TIMS Pre-Treatment
04/01/06-03/31/08
$26,708
Intellectual Merit of the Proposed Activity:

Zircon geochronology by SIMS (e.g., SHRIMP) and LA-ICP-MS methods routinely provide very large numbers of medium precision U-Pb dates at 10 – 50 micron spatial resolutions. These are the methods of choice for a wide range of problems ranging from complex crystallization histories recorded within individual zircon grains, to provenance studies using large populations of detrital zircon grains. The precision and accuracy of analyses on zircon "unknowns" is controlled not only by instrumental factors, but also by the quality and consistency of natural zircon "standards" used in the dating process. Improved zircon standards will be of enormous benefit in terms of improved precision, accuracy, and efficiency of SIMS and LA-ICP-MS U-Pb geochronology Objectives and Methods. The proposed research will take advantage of the new "CA-TIMS" method of zircon U-Pb geochronology (Mattinson, 2005). A major breakthrough that sets the CA-TIMS method apart is the understanding that high temperature annealing of natural radiation damage in zircons eliminates elemental and isotopic "leaching" effects that have severely limited the usefulness of partial dissolution techniques in the past. This understanding makes it possible to design experiments that completely strip off zircon zones that have lost Pb, then to analyze residual zircon that has behaved as a perfect closed system. CA-TIMS was originally developed to improve high-precision, high-accuracy TIMS zircon geochronology. However, the ability of the method to selectively remove zircon domains that have lost Pb, whether near grain rims, or deeper within grains, suggests its application to improving SIMS and LA-ICP-MS zircon standards. The proposed research will: 1) characterize zircon standards using detailed multi-step CA-TIMS analysis; 2) guided by the results of step 1), "pre-treat" aliquots of the standards by annealing, followed by sufficient partial dissolution to remove all domains that have lost Pb; 3) test these pretreated standards by round-robin SIMS and LA-ICP-MS studies at the Stanford SHRIMP-RG and Yale Excimer LA-ICPMS facilities; and 4) distribute the results, and pre-treated standards to the geochronological community.

Broader Impacts.

The proposed research will produce and distribute results, plus a suite of improved zircon standards to the international geochronological labs. The project provides method development support for an early career geoscientist (Hourigan), who is beginning a new faculty position at UC Santa Cruz. Furthermore, the analytical budget provides facilities support for day-to-day operation of the UCSB Isotope Ratio Mass Spectrometry Lab which is used by multiple graduate students. In addition, UCSB and UCSC undergraduate students will be actively engaged in all aspects of the proposed research. Students will learn a wide range of geochemical laboratory and instrumental techniques and data analysis, The project results will be disseminated via peer-reviewed journals, and will be of interest and value to the entire international geochronology community.

Mattinson
National Science Foundation
0549674 MJN03
Development of the CA-TIMS method: Refining U-Pb Zircon Geochronology
01/01/07-12/31/08
$240,919
Intellectual Merit of the Proposed Activity:

The precise and especially accurate measurement of geologic time continues to be one of most demanding requirements for deciphering a wide range of petrologic, tectonic, and paleobiologic problems. The U-Pb system in zircon is widely regarded as the "gold standard" of geochronology, but despite ca. a half-century of research into the behavior of this system, challenges in terms of open system behavior, decay constant uncertainties, and intermediate daughter isotope disequilibrium, etc., still remain. New techniques promise to move zircon geochronology to the next level, both in terms of understanding the behavior of U and Pb in zircon, and also in terms of zircon geochronology methods themselves.

Objectives and Methods:

The proposed research will continue development of the "CA-TIMS" method of zircon U-Pb geochronology, a new method for high-resolution geochronology (Mattinson, 2005), and to attack five inter-related problems: 1) developing a thorough understanding of the physics and chemistry of the CA-TIMS method at the micron scale; 2) understanding low-temperature fluid and radiation-damage mediated Pb loss in zircon, and its implications for both zircon geochronology and sequestration of radioactive waste in synthetic zircon or zircon-like materials; 3) investigation of the extent to which alpha-recoil processes produce small-scale local normal and reverse discordance in zoned zircons, and the limitations this might impose on high-accuracy geochronology; 4) evaluating the significance of 231Pa disequilibrium in producing 207Pb/206Pb age anomalies in igneous zircons; and 5) refining the decay constant of 235U, relative to 238U. A major breakthrough that sets the CA-TIMS method apart is the understanding that high-temperature annealing of natural radiation damage in zircons eliminates elemental and isotopic "leaching" effects that have severely limited the usefulness of partial dissolution techniques in the past. This understanding makes it possible to design experiments that completely strip off zircon zones that have lost Pb, then to analyze residual zircon that has behaved as a perfect closed system. Thus, the age-old problem of dealing with Pb loss appears to be resolved for most zircons. We now must turn to developing a better understanding of exactly how the CATIMS "works" (1, above). plus other problems (2-5, above) that limit: a) determination of concordance in zircons; b) the accuracy and precision of concordia intercept ages; c) understanding of the mechanisms by which zircons lose Pb; and d) determination of the suitability of synthetic zircon-like materials for sequestration of radioactive waste.

Broader Impacts:

One to two graduate students and two to three undergraduate students will be actively engaged in all aspects of the proposed research. Students will learn a wide range of geochemical laboratory and instrumental techniques, data analysis, data modeling, and will be working at the interface between basic and applied research. Interactions between the PI, graduate students, and undergraduate students will help develop teamwork skills. The project will further enhance the UCSB U-Pb geochronology lab. The project results will be disseminated via peer-reviewed journals, and will be of interest and value to the international geochronology community, where the CA-TIMS method is already having a major impact.

Niemi
National Science Foundation
EAR-0310252 NNN01
Paleotopography of an Evolving Extensional Orogen, the Central Basin and Range
10/01/03-09/30/06
$126,490
This project is designed to look at the topographic evolution of a portion of the central Basin and Range in the western United States during a period of late Cenozoic extensional tectonism. A variety of paleoaltimeters, geologic studies, and geophysical models have alternately predicted that the western United States has experienced either significant late Cenozoic uplift or substantial late Cenozoic lowering due to, or at least synchronous with, large magnitude intracontinental tectonism. In part these disparate results may be due to the geologic complexity of the western United States, and the fact that many of the study areas may have undergone differing tectonic histories in late Cenozoic time. The central Basin and

Range province, between Las Vegas and the Sierra Nevada is an ideal locality to study the paleotopographic evolution of the western United States because of 1) the wide spread and detailed geologic mapping that has been completed, resulting in a fairly complete palinspastic reconstruction of Tertiary extension; 2) recent passive and active seismic and other geophysical experiments in the region which delinieate the crustal structure and 3) studies that have examined the evolution of the sub-Basin and Range lithosphere through this same time period using xenoliths and the geochemistry of volcanic rocks. A newly developed paleoaltimeter based on basalt flow vesicles is well suited for approaching this problem due to the extensive coverage of basalts in this study area, the broad age range of the flows, and the desert environment which keeps them relatively fresh. We propose to sample approximately 40 sites for paleoaltimetry across a 300 km transect from the Sierra Nevada to the Spring Mountains, Nevada and determine the paleoelevations of these sites from late Miocene to Pliocene or Recent time.

This study has broad impacts for several reasons; first it bears strongly on the hypothesis that late Cenozoic epierogeny has affected climate, both in the United States and globally. The work also ties together years of work in developing map view palinspastic reconstructions of Basin and Range extension by adding a third dimension to the deformation, and finally, this study will be the first broad tectonic study using the newly developed altimeter. Collaborations with both the developers of the altimeter and the analytical facilities which process the samples should result in a stream lined process for future use of this altimeter, as well as testing and demonstrating its use in tectonic studies.

Polet
Department of Interior
05HQGR0003 PJU01/ PJU02
Installation and Further Development of a Fully Automated Global Centroid Moment Tensor Code at the National Earthquake Information Center
12/01/04-09/30/06
$98,292
We propose to install the autoCMT software, which computes fully automated global Centroid Moment Tensors and has been operating successfully at Caltech but will cease to be supported there in May 2004, at the National Earthquake Information Center in consultation with Dr. Paul Earle. For the past decade, this system has provided a valuable service as one of the few, if not only, providers of completely automatic reliable CMT solutions for worldwide events greater than a magnitude 5.5. We propose further improvements that will result in a more efficient, more reliable and faster system to deliver completely automatic CMT solutions for worldwide large earthquakes.

The existing systems at the NEIC either do not run fully automatically, do not determine a centroid time or location and/or are less suited for great earthquakes, because of their reliance on short period body waves, in contrast to the very long period surface waves used by the autoCMT. Thus the autoCMT system fulfills an important need at the NEIC and should be considered complimentary in nature to existing methods. The long period nature of the seismic waveform data the process uses as its input has the additional advantage that the method is relatively insensitive to the effects of timing errors, mislocation, and lateral heterogeneity. Through numerical and visual comparisons with existing methods, we show that the autoCMT determines reliable moment magnitude estimates and mechanisms, and performs particularly well for events greater than 7.0. It is especially notable that this fully automatic method performs equally well as its human reviewed counterparts for most large events, even with its input minimum of only 12 waveforms.

In consultation with Dr. Paul Earle and other personnel at the NEIC, we propose to further develop and implement our existing software and integrate it with routine NEIC operations. The proposed improvements to the system include: faster triggering, data access and processing; enhancing the readability and documentation of the code to facilitate its use and possible future modifications; adding a clear quality assessment of the solution and the addition to the code of improved data quality control of the waveform data, both prior to the CMT inversion as well through an iterative set of subsequent inversions.

This system represents an important improvement of rapid global large earthquake source and location characterization at the NEIC. It will deliver near real-time and accurate post-earthquake information on the likely impact of the earthquake, due to its size and location, the likelihood of surface rupture, its possible directivity (from the relative location of hypocenter and centroid location) and tsunamigenic potential (from the centroid time). The autoCMT solutions also have a valuable use as a near real-time starting point for full finite fault rupture inversions and strong ground motion predictions of great earthquakes and currently performs this function for Chen Ji's software at the NEIC.

Polet
Department of Interior
06HQGR0059 PJU03
Collaborative Research with University of California Santa Barbara and URS Corporation: Locating Seismic SLip using Long Period Waves
03/01/06-02/28/07
$19,798

Polet
Department of Interior
07HQGR0039 PJU04
Collaborative Research with University of California Santa Barbara and URS Corporation: Development and Implementation of a Continuous Detection, Location and Analysis System for Global Earthquakes Using Long Period Seismic Waves
01/01/07-12/31/07
$20,929
Modern day broadband seismic instrumentation and real-time data availability allow us to monitor the Earth in greater detail and over a much wider bandwidth than traditionally possible. The real time detection, location and magnitude determination of global earthquakes is crucial for seismic hazard mitigation and efficient emergency response after large global earthquakes. We propose to further develop and implement a continuous detection and location system for seismic events that uses waveform data at long periods, extending the current capabilities of the National Earthquake Information Center (NEIC) to cover a much wider spectrum. This new system can provide a reliable estimate of the moment of global earthquakes, like the recent Sumatra events, without saturating and thus is particularly useful for large earthquakes, which have proven to be difficult to analyze in near real-time using traditional body wave techniques. It can act as a back-up to the current NEIC monitoring software, detecting events, which are missed, or underestimated, by the current system. Particularly important in this regard are the so called "tsunami" earthquakes, long period earthquakes that excite anomalously large tsunami and are underestimated by the standard body waves techniques, but are correctly identified as potentially hazardous events by our analysis system. Furthermore, this long period method has the potential of

detecting anomalous deformation events that are currently not detected routinely. We have implemented a proof of concept system at the NEIC, using a very simple but powerful method of locating earthquakes using surface waves. It consists of a continuous progressive conversion of time series into spectrograms and the mapping of those spectrograms onto a grid of locations and origin times. It distinguishes itself from other methods that have been developed in recent years by its simplicity and its straightforward adaptation into a routine monitoring system. Computationally, the system takes a constant load approach, thus avoiding potential problems with large and intense earthquake sequences. Another advantage of this method is its flexibility to different spatial and time scales. The exact same code can be used to study global, continental or local regions by only changing the size and spacing of the grid, the time steps and the period range. This method also has the potential to be further expanded and eventually used to determine near real-time moment tensors or even more detailed source models, as has been shown by non real-time studies using similar back projection methods.

Our preliminary results, based on only a limited number of stations and a simple 1-D velocity structure, already show that the method can detect and locate earthquakes with magnitudes larger than 5.5 on a global scale. By applying the method to the Sumatra earthquake, we further demonstrate that it shows promise for determining a very rapid estimate of the directivity and finiteness of earthquakes and does not saturate. Using the Java tsunami earthquake as an example, we also show that the system can correctly identify the moment of long period earthquakes and thus their tsunami generating potential. Finally, we illustrate that the software can be used to detect and locate earthquakes missed by the current system, and can provide a reliable estimate of moment for underestimated events. We expect that our results will only improve further as we use more stations, better velocity models and fine-tune the methodology. We propose to further develop this system, coordinating with Dr. Paul Earle at the NEIC, by developing a trigger algorithm, station selection criteria, fine-tuning the filter parameters, performing an error and reliability analysis, improving its performance by adding more stations (and investigating the scalability) and finally collaborate with NEIC personnel to develop an on-line, real-time version of this system.

Polet
Department of Interior
7-8931-2210 PJG01
DI-U.S. Geological Survey –IPA
01/01/07-12/31/07
$18,979

Polet
National Science Foundation
0538263 PJN01
The Seismology of Shallow Intraplate Subduction Earthquakes: From Outer Risa to Interface
01/01/06-12/31/08
$106,961
A. Project Summary Intellectual Merit: The world's largest and some of its most destructive earthquakes occur on the interface between subducting and overriding plates, with the degree of interplate coupling playing an important role in their seismogenesis. Updip from this interface, the outer rise comprises an upwarping of the oceanic lithosphere just before it descends into the trench. Isacks and Molnar (1969, 1971), Isacks etal. (1969) and Oike (1971) established the characteristics of the stress regime within the subducting lithosphere and suggested that intraplate earthquakes serve as stress gauges for the large-scale

deformation involved in subduction zones. Polet (2003) recently compiled a new catalog of outer rise seismicity, confirming earlier results (Christensen and Ruff, 1983; Lay et al., 1989) by showing that normal faulting events occur preferentially after large interplate thrust events. However, no strong temporal bias exists for the compressional outer rise events, which hints that a more complex physical mechanism may be at work than simple elastic plate bending (Ward, 1983; Liu and McNally, 1993). A more likely candidate is a combination of downward plate bending and in-plane compression, with the former being the main contributor for outer rise tensional earthquakes and an elevated level of the latter being responsible for thrust faulting outer rise events. An inelastic analysis of lithospheric stress distributions by Mueller et al. (1996) predicts seismic behavior similar to that observed by Polet (2003). From these temporal and spatial relationships, it is clear that the state of stress in the subducting plate may change in response to interplate coupling. The seismicity record should reflect this and therefore shed light on the physical processes at work. The construction of a more complete and enhanced catalog of intraslab seismicity is proposed, extending the analysis of Polet (2003) to greater depths (150 km) and lowering the magnitude threshold from 6.0 to 5.5 for the relatively infrequent compressional outer riseevents. This catalog will aid in refining our understanding of the stress evolution within the subducting slab and the relationship between seismic coupling and intraplate seismicity. The next step of the proposed research is to apply a teleseismic P-wave modeling technique to refine the depths of the intraplate events to a higher precision and homogeneity. Subsequently a source spectralanalysis of the Mw>=6.5 earthquakes will be carried out to determine dynamic rupture parameters. These investigations will provide us with unique insight into a myriad of issues, including: the failure mechanism of intraplate and outer rise earthquakes, the state of stress in the subducting lithosphere, the origin of the hydration of the subducting plate and the mode of deformation of the outer rise. Bathymetric and seismic profiles across subduction-related trenches commonly show distinctive patterns of normal faulting on the outer trench wall (Masson, 1991). Hilde (1983) reviewed the occurrence of outer trench wall faulting and found it to be essentially ubiquitous. The relationship between this type of faulting and the structure and geometry of the subduction zone is still not clear(Hilde, 1983; Aubouin et al, 1984; Scholl et al., 1982). Obvious factors that may control the strike of these faults include the strike of the trench and any weakness in the subducting plate, such as the fabricresulting from oceanic spreading. We will relate these and similar observations from bathymetric and seismic trench profiles to intraplate earthquake occurrences and seismic moment release.

The main interest of the proposed research is in improving our understanding of the role of intraplate seismicity in the earthquake cycle, the mode of outer rise deformation and the role of pre-existing weakzones and dehydration in the generation of intraplate earthquakes. Our results will have further implications for several other disciplines. Improved knowledge of the temporal and spatial character of intraplate seismicity is an important first step towards the development of a new generation of models of subduction zone dynamics. The behavior of intraplate events in time, and their relationship to the earthquake cycle, may also be significant for intermediate term earthquake hazard assessment. Broader impact: The proposed research will broaden the participation of underrepresented groups since the P.I. of this proposal is an early-career female scientist. She has been a mentor to Anjali Tripathi, a high school student, for the past year through summer research and a state science fair project. If scheduling will permit it, Anjali will participate in aspects of the proposed research. A digital library of the earthquake catalogs will be created and made available in a timely manner through a website. The results will also be presented in conferences and workshops and published in a peer-reviewed journal.

Polet
URS Corporation
PA06S0001 PJP01
04/6/07-02/28/08
$16,000
Dr. Polet will provide input to the source characterizations used for the Probabilistic Tsunami Hazard Analysis. In particular, the delineation of subduction zone interfaces and earthquake sources along the outer-rise, the slip rates on these structures and estimates of earthquake-size distributions. The areas of interest are the circum-Pacific subduction zones that are relevant for tsunami hazard in North America and Hawaii.

Porter
National Aeronautics & Space Administration
NNG05GQ91G PSF01
Using skeletal microstructures to understand early animal biomineralization and phylogenetic relationships of early animals
10/1/05-09/30/07
$190,939
The Cambrian Explosion marks a major transition in Earth history, when advanced life first became an important component of the biosphere. We propose to use skeletal microstructure, preserved in submicrometer detail in many early animal fossils, to address two particularly problematic aspects of this diversification.

The first is the taxonomic affinities of the earliest animals. Although critical to understanding the early evolution of animal body plans, the relationships of most early animal fossils are problematic. Skeletal microstructure is just beginning to be explored as a source of phylogenetic information, but its use as such is highly controversial. The second issue is the sudden ? and independent -- appearance of skeletons in a diversity of animal clades in the early Cambrian. The triggers of this 'biomineralization event' are not well understood; the most widely accepted explanation ? that the appearance of macropredators drove skeletal diversification -- has never been directly tested. Skeletal microstructures can provide information about the mechanical strength (and thus predation-resistance) of shells, and thus can be used to assess whether predation was a dominant selective factor in the early evolution of shells.

Focusing our efforts on the diverse and well-known clade, Mollusca, we propose two key objectives: 1) Test the phylogenetic utility of microstructure in early animals by assessing congruence between morphological and microstructural characters in early molluscs; and 2) Test the hypothesis that predation drove early animal biomineralization by reconstructing the evolution of skeletal microstructures in early molluscs. To address these objectives, we will describe skeletal microstructures in a diversity of Early and Middle Cambrian molluscs and mollusc-like fossils from key formations in China, Siberia, and Australia; and use cladistic methods to reconstruct early molluscan phylogeny based on microstructural and/or morphological characters. Fossil specimens are housed at the PI's institution, at the Swedish Museum of Natural History, and at the Nanjing Institute of Geology and Paleontology.

A key research emphasis of NASA Exobiology is the evolution of advanced life, including the diversification of animals at the beginning of the Cambrian. Our research will contribute to two aspects of this diversification: the patterns of early body plan evolution and the triggers animal biomineralization.

Porter
University of California
SB060036 PSP02
From Stars to Genes: An Intergrated Study of the Prospects for Life in the Cosmos
10/01/05-10/31/07
$35,314
I proposed two research projects in UCLA's Astrobiology Proposal. The first was to study microfossil assemblages of early Cambrian animals from China with the goal of elucidating the early evolution of animal body plans (*Section 8.3.4*). The second was to conduct a paleoecological study of organic-walled microfossils from two mid-Neoproterozoic successions with the goal of understanding the relationship between Neoproterozoic environmental change and the diversification of eukaryotic organisms (*Section 8.2.3*). During the course of this work we have discovered an unusual species, *Bavlinella faveolata*, at several horizons in both successions. This species occurs in dense, monospecific assemblages in deeper water facies, but is not found in the more diverse fossil assemblages that occur in shallow-water facies, suggesting that *B. faveolata* thrives in conditions inimical to other species. Particularly significant, it is also known from *synglacial, shallow water* facies associated with the older of the two 'snowball Earth' glaciations. Originally assumed to be the remains of cyanobacteria, it has recently been hypothesized that *B. faveolata* represents an anoxygenic photosynthetic bacterium that thrived in euxinic conditions. The goal of Robin's research is to test this hypothesis, using light and electron microscopy to reconstruct the morphology of this fossil in detail. She will also survey synglacial mudstones and shales associated with other 'snowball Earth' successions to determine if *B. faveolata* blooms were widespread in glacial oceans. This work will be integrated with biomarker and other geochemical analyses (conducted by me and my colleagues) that will look for evidence of euxinic conditions recorded in *B. faveolata*-hosted rocks.

Sorlien
National Science Foundation
OCE-0327273 SCN02
Collaborative Research: Basin Evolution Along Continental Transforms: Nested Hi-resolution Multichannel Survey in the Marmara Sea
03/01/04-02/29/08
$69,972
Basins form along continental transform faults. Strike-slip faults are carefully balanced with fault direction and fault slip parallel. Thus they are susceptible to changes in kinematics and fault orientation and can easily develop zones of compression or extension. Strike-slip faults are characterized by motion parallel to their strikes, so that changes in kinematics and fault orientation result in zones of compression or extension. Extensional basins along transforms form at different scales and levels of complexity. The largest systems can be made up of multiple basins. Under finite strain, these basins the stress field changes and this basin must evolve. Do continental transform basins evolve from a broad, diffuse zone towards a single-through going fault? Do they become more complex, or is complexity a stable characteristic? On what time scale does this occur, and what is driving this evolution?. For example, are space problems at fault bends solved by changes in slip on a single fault, or, does slip partition so that pure strike-slip motion occurs through bends with space problems solved by subparallel normal or reverse faults?

We propose to study basin formation in Marmara Sea along the North Anatolia fault system. There are a number of reasons why the 75 x 200 km basin Marmara Sea is the best place to study transform basin formation and the evolution of a continental transform fault. These reasons include the fact that most of the system is covered by water allowing high quality MCS data to be rapidly acquired, yet is surrounded by outcrop and it also contains islands. The deformation rates along the North Anatolian fault in Marmara Sea are high, and, the system may have initiated in late Miocene or later, so evolution of the system is rapid. There has been a lot of international interest in the area since the devastating and deadly 1999 earthquakes, resulting in a lot of abundant available data, complementary to what we propose.

We propose to acquire of a nested grid of high-resolution MCS and gravity data, and integrate these data with existing and planned data. This work will be undertaken in collaboration with scientists from MTA, Istanbul Technical University and the Marmara Research Center in Turkey, the Istituto di Geologia Marina in Bologna, Italy, as well as a scientist from Greece. The ongoing research on the Marmara Sea has included collection of collected swath bathymetry, coring and a range of shallow seismics that image the near-surface deformation from the present-day kinematics. Recent deep-penetration reflection and OBS refraction seismic are imaging the crustal structure and Moho. What is missing from the Marmara Sea is a stratigraphic framework that can enable the tectonic evolution of the Marmara Sea to be unraveled. Existing moderate resolution MTA and older industry MCS data provide groundwork, but have insufficient coverage and resolution to answer questions about the basin evolution.

We will collect high-resolution MCS data during a 35-day leg on the *R/V Maurice Ewing* using a pair of GI guns and a 96-channel 1200-m streamer to obtain images of the strata in the upper 2-3 km with 3-5 m resolution. During the first part of the cruise we will collect a 5x7.5 km grid of high resolution MCS data over the entire Marmara. Our aim is to develop a stratigraphic framework that will allow us to correlate sequences between basin and develop a relative temporal framework. During the second part of the cruise, we will collect several closely-spaced (1x2 km) grids of critical regions in order to elucidate the tectonic history of the Marmara Sea and its implications for the evolution of strike-slip basin systems. These grids will detail the stratigraphic record of deformation and fault motion at crucial bends and junctures in the fault system. Onboard processing will enable us to adjust our track based on survey results. The results of this cruise will be integrated with the other ongoing efforts at different spatial scales to help develop a coherent model the of the formation and evolution of the Marmara Sea.

Intellectual Merit:

This project will result in a better understanding of the evolution of strike-slip basins. We will investigate how basins and uplifts are related to different classes of master-fault structures, such as jogs or bends. Our strategy is to study the Marmara Sea basins through their evolution and thus reveal how they have responded to known external factors. Systematic differences between short and log-term structure may reflect changes in the effects of tectonic stress, gravity, and sediment load during the growth of the basin, providing insight in the into the mechanisms that control .strike-slip basin development.

Broader Impacts:

The city of Istanbul, with more than 12m people and a majority of buildings constructed without complience to building codes is more likely than not to experience strong shaking from a large earthquake in the Marmara Sea during the next 30 years. Thus hazard, exposure, and vulnerability are all unusually high and the resulting risk is huge and a major challenge. An interdisciplinary group at Columbia University's Hazard and Risk Research Institute is working with similar organizations in Turkey and elsewhere to evaluate this risk and to design realistic programs to decrease it. One of the PIs has pursued basic earthquake science in the Marmara Sea area since the first destructive earthquake in 1999 and is also taking a major role in the risk evaluation and reduction effort. Risk-reduction measures in a major population center in advance of an earthquake would mark a major achievement that could guide future efforts worldwide. This project would provide a better understanding of current fault segmentation and temporal history of the fault system that will directly apply to the risk-reduction effort.

Spera
National Science Foundation
ATM-0425059 SFN09
ITR(ASE)-(sim): Collaborative Project: Virtual Laboratory for Earth and Planetary Materials Studies
10/01/04-09/30/08
$206,000
This project aims to enhance the development of a novel branch of computational materials science: the theory of earth and planetary materials. Its flourishing in the last decade was enabled by the maturing of computational condensed matter physics, the development of reliable and portable 'first principles' software for materials simulations, and powerful computer systems. Today it is possible to investigate realistically the physical and chemical properties of complex materials at conditions typical of planetary interiors that were unthinkable ten years ago. Only independent determination of these properties in these materials at the relevant conditions can provide a basis for 1) an interpretation of observational data in the context of likely planetary processes, 3) a basis for a discussion of their internal chemical and physical states, and 2) critical input for more sophisticated and reliable modeling of their interiors. This task is still exceedingly challenging to experiments but fundamental to advance our understanding of planets to new levels.

This project will reach across and assemble efforts from different disciplines in this inherently interdisciplinary research field. Most importantly, it will explore emerging computational technologies, such as computational stirring, grid computing, and visualization to bring state-of-the-art techniques from computational materials physics to new levels of performance. This is most needed to improve reliability and the level of complexity required in simulation of planetary materials. At UCSB PI FJ Spera will use large scale Molecular Dynamics codes in his possession to study the role H_2O plays in molten silicates at elevated temperature and pressure. This work will be done in the Magma Rheology Lab at UCSB and at NERSC.

Spera
National Science Foundation
EAR-0440057 SFN10
Collaborative Research: Internally-Consistent Model for Trace and Major Element Evolution in Open System Magma Bodies: Merging EC-RAFC and MELTS
01/01/05-12/31/08
$197,133
The objective of this research is to develop a computational geochemical tool, the Magma Chamber Simulator (MCS), to describe the major and trace element, isotopic, mass, and thermal evolution of open system magma bodies undergoing simultaneous recharge, assimilation, and fractional crystallization. The MCS provides a self-consistent thermodynamic description of a composite magma-host rock-recharge system, subject to energy and mass exchange during the approach to thermal equilibrium. The MCS couples multicomponent phase equilibria to trace element and isotope evolution by appropriately linking the energetics of partial melting and assimilation, recharge, and fractional crystallization to major and trace element species conservation and Gibbs energy minimization or entropy maximization via a set of coupled non-linear differential equations. The MCS is constructed by reformulation and integration of

two extant modeling tools, MELTS and EC-RAFC. The MCS will track the geochemical and petrological evolution of solids and liquids in an open-system magma chamber. The MCS, applicable to a wide variety of lithospheric magmatic systems, is poised to address questions relevant to modern igneous petrology/geochemistry. An overview of several of these questions, in the context of studies in classical settings such as ocean island magmatism (Hawaii), subduction zone magmatism (Arenal), continental flood basalt magmatism (Parana), and layered mafic intrusions (Bushveld Complex) is provided. The MCS software will be made available via the Web as a Microsoft Excel spreadsheet. Within this spreadsheet, the user will also be able to run a stand-alone version of MELTS. MCS will serve a user base as diverse as professional researchers and undergraduate petrology students. Several undergraduates geochemical-petrology modeling exercises, including case studies utilizing published data, will be developed using the MCS software tool and made available on the Web.

The **intellectual merit** of the proposed activity centers on the well-documented idea that magma chambers are inherently open systems subject to simultaneous contamination, recharge and fractional crystallization. At present, there is no single, self-consistent, rigorous model for simulating the phase equilibria, major and trace element, and isotopic evolution of liquids and solids in open systems. Development of such a model would allow field, geochemical, petrological, and geochronological studies of magmatic systems to be placed in a quantitative framework that would enable predictions about the behaviors of magmatic systems. Through application of the MCS to the diverse array of magmatic systems represented on Earth, progress can be made on the fundamental question of how magma diversity is achieved. Petrogenetic studies demand a holistic approach, and the MCS, which will allow constraints from phase equilibria to be incorporated with trace element and isotopic information in a dynamic context, will provide petrologists and geochemists a reference model applicable to natural magmatic systems.

The **broader impacts** resulting from the proposed activity are that the geochemical and petrological community will be provided with a user-friendly desktop computational tool for systematically, self-consistently and quantitatively investigating the evolution of dynamic, open-system magma bodies. This tool, which will be available on a number of web sites, will be of use not only to professional researchers but also to undergraduate geology students. As part of the outreach activities, exercises for undergraduate/graduate petrology classes will be developed in collaboration with students. Students involved in research activities will be exposed to computational modeling as well as use of geologic data to answer relevant questions in igneous petrology. It is anticipated that undergraduate and graduate students will work as teams on aspects of this work. Thus, this study will not only impact the research of a large number of professional petrologists/geochemists, but it will also contribute to the training of students in research, curriculum development, and collaborative endeavors.

Steidl (SJP10)
Carnegie- Mellon University
NEESR-SG: High-Fidelity Site Characterization by Experimentation, Field Observation, and Inversion-Based Modeling
10/01/06-09/30/10
$311,636
The aim of the proposed research is to develop the capability for characterizing the detailed geological structure and mechanical properties of individual sites and/or complete basins by means of integrated in-situ field testing techniques, observation of ground motion from actual earthquakes, and inversion-based

modeling. The two most important types of mechanical properties that we will seek to identify are the seismic velocities (primary (P-wave), and shear (Swave)), and the intrinsic attenuation of the various soils. To attain such characterization capabilities, we will exploit the resources afforded by two NEES sites, the permanent and temporary instrumentation at Garner Valley in CA (nees@UCSB) operated by the University of California at Santa Barbara (UCSB), and the mobile shakers operated by the University of Texas at Austin (nees@UTexas), respectively. It is a central goal of the proposed work to seek to demonstrate and validate our development by characterizing a large portion of the Garner Valley in Southern California as a prototype application. Geological and geotechnical materials, soil and rock, represent the largest fraction of all materials that impact the performance of the built environment during earthquakes. The geological structure and geotechnical materials play a critical role in the generation of ground motion, and, consequently, on determining the spatial extent and severity of damage during earthquakes. Yet, the geological and geotechnical materials are the least investigated, even though they are the most variable and least controlled of all materials in the built environment. The primary reason is that since soils cannot be easily accessed, their properties can only be inferred indirectly. Currently, geomaterials in geotechnical earthquake engineering applications are characterized with essentially the same (or updated versions of) general testing methods and modeling techniques that were used 25 years ago. These methods rely on testing a small number of specimens in the laboratory and conducting a limited number of field tests in which one presupposes that the site under investigation consists of a horizontally-layered medium. Generally, field tests range from simple penetration testing to more sophisticated in-situ seismic measurements of small-strain material properties. There is a critical need to advance beyond the current dependence on small-scale laboratory testing and limited field tests, which postulate that soils at a site are made up of horizontal layers, in order to reduce the level of uncertainty that currently exists in the estimation of geological and geotechnical material properties.

We have assembled a research team that spans the entire spectrum of the expertise needed to bring to fruition the proposed work: the team includes geotechnical engineers, earthquake engineers, seismologists, computational mechanicians, and mathematicians. Members of this team have been working for a number of years on developing field testing and observational techniques, on the one hand, and on modeling techniques, on the other, in order to improve our capability for performing site and basin characterization. Specifically: Researchers at the University of Texas at Austin (UTA) were instrumental in developing the cross-hole seismic method for in-situ measurement of shear and compression wave velocities. More recently, we developed the spectral analysis of surface wave (SASW) method, a non-invasive technique for estimating the distribution of shear-wave velocities in horizontally-layered soils. All measurements are made on the ground surface, making it much less costly than methods that require boreholes. Because of its non-invasive nature, accuracy, and speed of execution, the SASW has been referred to as one of the most significant recent advances in shallow seismic exploration ([1]). To further advance our ability to characterize geologic structures, under a NEES Equipment award 1, UTA has developed large-scale field equipment (nees@UTexas) that is capable of applying larger loads and desired load programs in time. This will result in outgoing waves that will generate larger strains and will travel farther and deeper than has been previously possible. In parallel, under a recent CAREER award2 we are developing the algorithmic framework and the experimental protocols that will allow us to profile relatively small sites of non-layered stratification. Team members from the University of California at Santa Barbara (UCSB) and the Georgia Institute of Technology have been studying the variation of site response during earthquakes, using permanent arrays of sensors on the surface and on boreholes, as well as dense arrays of portable accelerometers deployed following large earthquakes. We have developed a hybrid global-local optimization procedure for downhole seismogram inversion and have used it to estimate soil properties for horizontally-layered media with refined near-surface discretization. The focus has been on the Garner Valley, and more particularly on the Garner Valley Downhole Array (GVDA), which consists of a set of downhole strong motion instruments, but have also employed the hybrid inversion scheme to estimate the elastic and average strain-dependent dynamic soil properties for strong and weak motion events recorded in Japan by the strong motion array Kik-net. The Garner Valley array is located in a highly seismic region that is susceptible to a M 6.5 or greater earthquake, and where hundreds of earthquakes of widely varying magnitudes have been recorded since the array was deployed in 1989. The existence of the instrumented boreholes, the high seismicity, and the ready availability of records is a major reason why the GVDA and the entire valley are ideally-suited as a testbed for monitoring ground motion and for performing earthquake ground motion studies. A NEES Equipment award 3 to Brigham Young University (in partnership with UCSB and the University of Southern California) established two permanently instrumented field sites, with one of them at the GVDA. As part of this award, the instrumentation at this site has been upgraded and enhanced for real-time data transmission through a high-performance network. This greatly adds to the GVDA as a field site for monitoring ground motion from in-situ tests and earthquakes.

The research group at Carnegie Mellon University (CMU) (with one of its members now at UTA) has concentrated on developing the capability for generating realistic inversion-based computational models of complex basin geology, and on using this capability to model and forecast strong ground motion during earthquakes in such large basins as Los Angeles (GLAB). Using the Southern California Earthquake Center (SCEC) Velocity Model, and our forward wave propagation software, we have been able to match observed ground motion from past earthquakes in GLAB at some locations, but not at others. This discrepancy is likely the result of uncertainties in both the seismic source and the geological model. This has led us to the inverse problem: we wish to estimate the two- and three-dimensional soil property distribution (as opposed to piecewise horizontal layers) that results in a predicted response that most closely matches observed records from earthquakes. This is exactly the same problem that needs to be solved for site characterization, except that the records then come from different sources, including active field tests. This suggests that the same techniques applied for basin inversion could be used for site characterization. The inverse problem, however, is significantly more difficult to solve than the associated forward wave propagation problem. Even when the forward problem is well-posed, the inverse problem is ill-posed and characterized by multiple solutions. Specialized algorithms are therefore required; to this end, we build on a decade of development. Specifically: the National Science Foundation (NSF) established a Grand Challenge Applications Group (GCAG) in 1993 dedicated to earthquake ground motion modeling (Quake Project). The work under this grant was devoted exclusively to the forward problem. The group's work was extended in 1999 through an NSF Knowledge and Distributed Intelligence (KDI) group grant 4, under which we initiated our work on the inverse problem, and in 2003, through an Information Technology Research (ITR) grant5, to concentrate on the inverse problem. For our forward and inverse modeling work under the auspices of these grants, we have received several awards, including the 2003 Gordon Bell Prize for Special Achievement Based on Innovation at Supercomputing 20036. In parallel, recent work from the research team at the University of Texas at El Paso (UTEP) has focused on algorithms for large-scale optimization problems, which are equally applicable to the material property reconstruction inverse problem arising in site characterization. In particular, the UTEP team has developed interior-point trust-region algorithms that, in the context of the material identification problem, hold the promise of accelerating the search for the true material profile.

The present proposal builds on the current research and accomplishments of the various sub-teams, but broadens the scope to encompass the complexity needed to create and disseminate methodologies that integrate field experiments and earthquake observations with wave-based three-dimensional inversion in order to characterize rapidly and with high fidelity the three-dimensional properties and structure of individual sites and entire sedimentary basins. To realize this vision and to address the new modeling challenges, we propose to pursue a concerted, unified effort in (a) field testing with the large-scale equipment at UTA (nees@UTexas); (b) data gathering from earthquake observations (nees@UCSB); and (c) online inversion, with particular application to Garner Valley and the GVDA. Our reasons for choosing the GVDA and Garner valley have been stated above. Our purpose for doing inversion online is that this will permit us to use the results of one field test in a series to help design and steer the next field experiment in the series. In the past, each of the PIs has worked either on experimental activities with some limited level of simulation, or on large-scale simulation techniques, or on algorithmic development. But no one has previously attempted to integrate the experimental, observational, and modeling techniques to the extent required to achieve our ultimate goal of creating and validating an experimental/simulation methodology for realistic two- and three-dimensional site characterization.

Nor are the integration of the state-of-the-art experimental and computational activities we propose the focus of any of our currently active NSF awards (similarities and departures are noted in the body of the text, as appropriate). We have the background, experience, and knowledge required for this ambitious, yet ultimately doable, task. That is why we seek support under the NEESR-SG program. We are aware that in most practical situations, engineers and seismologists will not have access to the different active vibration techniques and vast amounts of surface and borehole data that we will have for our project from the experiments and earthquake observations. For many applications involving a particular site, it is unlikely that relevant earthquake observations will be available. Therefore, our proposed methodology must be sufficiently robust to provide a realistic reconstruction of the geometrical and mechanical features of the site, based *only* on field data from active tests. Seismic data, if available, can be used to characterize a much larger and deeper region, up to a complete basin. Thus, one important objective of this project is to *compare* the quality of the inversions that can be obtained by using only selective amounts of data, from different sources of excitation. This will allow us to analyze hierarchically the fidelity of the models that can be derived from different tests and types of data. Among the parameters to be examined are: the range of the frequencies of excitation; number and separation of the recording instruments (optimal sensor placement); whether these instruments are located on the free surface or within boreholes; the type and strength of the source, and whether the source is active (mobile shaker) or passive (earthquake). In order to achieve our goal we will be faced with a number of challenges that will require advances that go well beyond the scope of our current projects. For instance, many of the theoretical issues related to seismic inversion are being studied under two of the projects mentioned earlier 7. However, including soil damping in the inversion process simultaneously with the material velocities, and the online inversion with the intent of steering the experiment based on early imaging results, will pose a number of additional challenges. Similarly, the new large-scale mobile shakers enable us to generate waves that travel farther and deeper than had previously been possible. However, this makes it questionable to represent the affected soil deposits by a flat-layered system as, for example, the SASW method does, thus making it necessary to deal with the true, lateral and vertical complexity of the geometry and heterogeneous nature of the soil deposits. To address such issues we will divide our study into various steps, by considering first two-dimensional, and then three-dimensional models. This approach will help minimize the risk associated with dealing with the highly challenging three-dimensional characterization all at once. These and other challenges are discussed in the following sections, together with our current capabilities, research issues, and proposed work.

Steidl

Department of Interior
06HQGR0038 SJU01
Geothechnical Array Data Analysis at the ANSS Anchorage site and NEES/ANSS Integration
01/01/06-06/30/07
$22,813
Objectives:

- Attenuation and amplification analysis of vertical array data at the Delaney Park Array DPK) in Anchorage for use in ground motion simulation studies.
- Integration of the DPK data into the EES/UCSB permanent field sites cyber infrastructure.

Significance of the Project to NEHRP Goals:

This proposal intends to take advantage of the newly instrumented ANSS engineering seismology test site at Delaney Park in downtown Anchorage, Alaska. The research we are proposing is to use recorded data at DPK and a newly developed hybrid inversion technique to estimate the attenuation and amplification properties of the soil column as the waves propagate up through the multi-level strong motion array. The attenuation behavior of near surface soils becomes important as we move from long period simulations of ground motions to hybrid or broad-band calculations of ground motions that include the effects of the near-surface geology. We intend to provide the attenuation results to the groups developing the 3D velocity models, as they will be useful to modelers who are pushing the frequency limits of ground motion simulations. This geotechnical site information can be extended to other alluvial sites with similar material properties. The EHP encourages research proposal that involve collaborative research between ANSS the NSF's MRE facilities. This proposal will also establish a collaboration for the DPK site between the NSF George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) "Permanently Instrumented Field Sites" program at UCSB and the USGS ANSS and NSMP programs. The permanent field sites are built to improve on our methods for simulation of strong ground motion and dynamic soil behavior using the critical constraint data (the insitu observations) needed to calibrate these simulation methods. Under this project, the data from the DPK site will be integrated into the UCSB NEES program, and made available to the earthquake engineering community by linking the data acquisition systems into the cyber infrastructure developed by the NEES program.

Contribution to reducing losses from earthquakes:

This project will advance discovery by providing dissemination of the Anchorage array data in real-time to the wider earthquake engineering community through the NEES cyber infrastructure. The benefit to society stems from the increase in the number of available test sites, adding variability in the soil types and geometric configurations needed to provide data from the range of site conditions commensurate with those commonly encountered in engineering design of the built environment. Improvements in the ability to simulate soil behavior at a variety of site conditions translates into more accurate input motions for the practicing engineer, leading ultimately to more cost effective design through performance (simulation) based engineering design.

Steidl
Department of Interior
06HQGR0134 SJU03
Geotechnical Array Data Analysis at the Hollister Earthquake Observatory and NEES/ANSS Integration
03/01/06-06/30/07

$15,000

Objectives:

- Attenuation and amplification analysis of vertical array data at the Hollister Earthquake Observatory (HEO) for use in ground motion simulation studies.
- Integration of the HEO data into the NEES and ANSS real-time systems providing researchers with open access to the data.

Significance of the Project to NEHRP Goals:

This small proposal intends to leverage the existing engineering seismology test site at HEO, a multi-million dollar investments in earthquake engineering research infrastructure. This site was built and operated for a decade by the Japanese construction firm, Kajima, Corp. It was recently donated to UCSB by the Japanese in recognition of our experience in maintenance and analysis of geotechnical strong motion arrays. The research we are proposing is to use previously recorded data at HEO and a newly developed hybrid inversion technique to estimate the attenuation and amplification properties of the soil column as the waves propagate up through the multi-level strong motion array. The attenuation behavior of near surface soils becomes important as we move from long period simulations of ground motions to hybrid or broad-band calculations of ground motions that include the effects of the near-surface geology. We intend to provide the attenuation results to the groups developing the 3D velocity models, as they will be useful to modelers who are pushing the frequency limits of ground motion simulations. This geotechnical site information can be extended to other alluvial sites with similar material properties. The EHP encourages research proposal that make use of NSF's MRE facilities. This proposal will also establish a collaboration for the HEO site between the NSF George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) "Permanently Instrumented Field Sites" program at UCSB and the USGS ANSS and NSMP programs. The permanent field sites are built to improve on our methods for simulation of strong ground motion and dynamic soil behavior using the critical constraint data (the insitu observations) needed to calibrate these simulation methods. Under this project, the data from the HEO site will be made freely available in real-time to the earthquake engineering and seismological community by linking the data acquisition systems into the cyber-infrastructure developed by the NEES program and into the ANSS/NSMP real-time systems.

Contribution to reducing losses from earthquakes:

This project will advance discovery, providing unlimited access for the entire research community to data that has historically been available to only the scientists and engineers of the large Japanese engineering firms. The benefit to society stems from the increase in the number of available test sites, adding variability in the soil types and geometric configurations needed to provide data from the range of site conditions commensurate with those commonly encountered in engineering design of the built environment. Improvements in the ability to simulate soil behavior at a variety of site conditions translates into more accurate input motions for the practicing engineer, leading ultimately to more cost effective design through performance (simulation) based engineering design.

Steidl
Department of Interior
06HQGR0135 SJU02
Geotechnical Array Data Analysis at Borrego Valley and NEES/ANSS integration
03/01/06-06/30/07
$20,000

Objectives:

- Attenuation and amplification analysis of vertical array data at the Borrego Valley Downhole Array (BVDA) for use in ground motion simulation studies.
- Integration of the BVDA data into the NEES and ANSS real-time systems providing researchers with open access to the data.

Significance of the Project to NEHRP Goals:

This proposal intends to leverage the existing engineering seismology test site at BVDA, a multi-million dollar investments in earthquake engineering research infrastructure. This site was built and operated for a decade by the Japanese construction firm, Kajima, Corp. It was recently donated to UCSB by the Japanese in recognition of our experience in maintenance and analysis of geotechnical strong motion arrays. The research we are proposing is to use previously recorded data at BVDA and a newly developed hybrid inversion technique to estimate the attenuation and amplification properties of the soil column as the waves propagate up through the multi-level strong motion array. The attenuation behavior of near surface soils becomes important as we move from long period simulations of ground motions to hybrid or broad-band calculations of ground motions that include the effects of the near-surface geology. We intend to provide the attenuation results to the groups developing the 3D velocity models, as they will be useful to modelers who are pushing the frequency limits of ground motion simulations. This geotechnical site information can be extended to other alluvial sites with similar material properties. The EHP encourages research proposal that make use of NSF's MRE facilities. This proposal will also establish a collaboration for the BVDA site between the NSF George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) "Permanently Instrumented Field Sites" program at UCSB and the USGS ANSS and NSMP programs. The permanent field sites are built to improve on our methods for simulation of strong ground motion and dynamic soil behavior using the critical constraint data (the insitu observations) needed to calibrate these simulation methods. Under this project, the data from the BVDA site will be made freely available in real-time to the earthquake engineering and seismological community by linking the data acquisition systems into the cyber-infrastructure developed by the NEES program and into the ANSS/NSMP real-time systems.

Contribution to reducing losses from earthquakes:

This project will advance discovery, providing unlimited access for the entire research community to data that has historically been available to only the scientists and engineers of the large Japanese engineering firms. The benefit to society stems from the increase in the number of available test sites, adding variability in the soil types and geometric configurations needed to provide data from the range of site conditions commensurate with those commonly encountered in engineering design of the built environment. Improvements in the ability to simulate soil behavior at a variety of site conditions translates into more accurate input motions for the practicing engineer, leading ultimately to more cost effective design through performance (simulation) based engineering design.

Tanimoto (TTN01)
National Science Foundation
Ocean-Solid Earth Interaction: Seismic and Satellite Data
07/01/04-06/30/06
$171,543
During the past few decades, it has become clear that the Earth's components - atmosphere, ocean and solid Earth - interact in complex ways on various time scales. Seismograms reveal such interactions,

mainly on days without large earthquakes. One example is the continuous background oscillations that was first reported in 1998, whose cause is actually still unknown.

The atmospheric excitation hypothesis was pursued by a few groups, including this PI, but it is becoming clear that the power through the direct-forcing mechanism by atmosphere is not sufficient. The correlation length in atmospheric pressure changes, which is proportional to modal amplitudes in the stochastic excitation mechanism, is not 10 km as was originally assumed (approximately the scale height of atmosphere), but is rather like a few hundred meters at frequencies of about 3 mHz. On the other hand, ocean waves seem to have sufficient energy in the form of infragravity waves in the frequency band between 3 and 15 mHz. Furthermore, the infragravity mechanism seems to be able to explain the overall characteristics of spectral hape in this frequency band, which has a broad peak at about 7-9 mHz.

This is a two-year proposal, which will evaluate this ocean-wave excitation hypothesis by theoretical modeling and observational data analyses. Our efforts will focus on: (i) search for the source location of excitation, because there are some indications in data for a rather localized source for a given (short) time interval, (ii) modeling geographic variations in spectra through comparison between theory and data, and (iii) characterization and monitoring of seismic and satellite data, including six-months and annual components.

Intellectual merit:

The goal of this proposed study is to understand the cause and mechanism of ubiquitous seismic oscillations and to learn the implications to mechanical coupling between the ocean and the solid earth. Thus, it represents a scientific pursuit for trying to understand a novel enigmatic phenomenon. The data occupy a unique frequency band between about 3 and 15 mHz and may add a new dimension to our understanding of mechanical couplings in the Earth system. The phenomenon may be of interest to a broad range of earth scientists. As with any other scientific pursuit of new knowledge, it may have some future benefit. For example, it may be critical for detection of slow earthquakes in the future, because the continuous oscillations are the principal source of noise in this frequency band. There is some hint that previous slow-earthquake studies have been hampered by these oscillations. Understanding the nature of this phenomenon will give us insight on how to reduce noise and enhance other signals in the same frequency band.

Broader impacts:

This study takes advantage of seismic and satellite (ocean) data whose complimentary use have not been examined before. Use of seemingly unrelated data will undoubtedly become important in geosciences in order to advance our understanding of the Earth as a dynamically connected system. The project will hire and educate a graduate student.

Wyss
National Science Foundation
DEB-0317177 WAN02
Collaborative Research: Andean Fossils Mammals - Phylogenetic and Geologic Implications
10/01/03-09/30/08
$150,004
The bizarre mammal fauna arising from South America's isolation as an island continent for most of the Cenozoic (65-0 Ma) has captivated evolutionary biologists since Darwin's time. Over the past decade the PI's have discovered numerous highly unexpected new faunas from the Andes of central Chile. These

faunas illuminate several long standing phylogenetic, evolutionary, and biochronologic problems; calibrate key intervals of the Cenozoic South American land mammal sequence; and help elucidate mammalian evolution across a broad time span (at least 40-15 Ma). The first of these assemblages to be uncovered, the ~31.5 Ma Tinguiririca Fauna, is remarkable in many ways, including a) the notable completeness of the >400 specimens collected to date; b) its diversity (>25 taxa, most new); c) that it represents the first Paleogene mammals known from west of the Andean divide and a new South American Land Mammal ìAgeî; d) the oldest known caviomorph rodents (an allochthonous immigrant group); e) the earliest hypsodont-dominated fauna known globallyóthereby supporting the early appearance of open grassland habitats in South America; and f) clarifying events around the Eocene/Oligocene boundary (~34 Ma) and its associated climatic, paleoenvironmental and biotic changes. Many of the numerous discoveries we have made subsequently (spanning at least 4° north-south of Tinguiririca) promise to be equally significant. In addition to their paleontological importance, these Andean faunas are providing the first radioisotopic calibration of several parts of the standard SALMA sequence and have helped revolutionize understanding of the geologic history of this region. The realization that fossils occur throughout a thick sequence of volcanic sediments of the central Andean Main Range has brought to light a major new repository of information about South American mammal evolution, one that is virtually untapped and enormous in scope. These deposits thus hold the potential to generate one of the most complete and well-calibrated records of South American mammal evolution known, an objective we intend to advance through this proposed research.

The current project builds on our previous successes in three major directions. First, the project team will further extend its *field collection and exploration* program to discover additional localities and faunal horizons, and to augment sampling from several existing ones. Second, the team will *establish an integrated geochronologic framework*, emphasizing high-precision 40Ar/39Ar dating (complemented by stratigraphy, biochronology, and magnetostratigraphy) for the most important of the dozen existing faunas, and any that are newly identified during the proposed work). And third, the project team will use the exceptional new cranial and postcranial material of Eocene-Miocene taxa in these faunas to *undertake rigorous studies of the phylogeny and diversification of several major endemic South American mammal clades* (basal caviomorph rodents, argyrolagoids and other major groups of ameridelphian marsupials, and interrelationships of notoungulate ìfamiliesî). These systematic analyses will develop from continued preparation and description of these diverse, well-preserved fossils, and rigorous alpha taxonomic studies and higher-level phylogenetic analyses of constituent taxa. Collectively, these areas of inquiry will clarify biotic, environmental, and geologic events during crucial intervals of South American land mammal evolution, and will refine currently poorly-constrained parts of the geochronology of the SALMA sequence. These advances are essential for better understanding the timing and rates of mammalian diversification.

Our project, as in the prior NSF-supported research, should have significant societal impacts, ranging from field and research training of 2 excellent US women graduate students, to student training and informal educational outreach in Chile (our partners in this work), through exhibits and other educational programming reaching the Field Museum's 1.6-2.3 million annual visitors.

SCEC AWARDS

Archuleta
University of Southern California
069203 ARS04

ITR/AP: The SCEC Community Modeling Environment: An Information Infrastructure
10/01/01-09/30/06
$228,051
The first year's efforts focus on simulating ground motion for scenario earthquakes in order to improve probabilistic seismic hazard analysis (PSHA)-Pathway 2 in the ITR proposal. We will complete the validation of a three-dimensional viscoelastic finite difference (FD) code that can be used to simulate low-frequency ground motion for a wide range of scenario earthquakes. This FD code will be wrapped and made available for execution on the web as a SCEC wave propagation community model. The implementation will allow coupling to user-supplied rupture models as part of Pathway 3 in the ITR proposal. Because the PSHA relies on high-frequency as well as low-frequency ground motion, we will explore hybrid methods that can extend the frequency range of the computed ground motion to produce synthetic broadband time histories. For two scenario earthquakes we will compute multiple realizations of broadband ground motion time histories from which statistical parameters can be computed. These statistical parameters will be compared to estimates based on empirical methods used in PSHA.

Archuleta
University of Southern California
PO 094119 and PO 105819
SCEC Deputy Director
10/01/2003-01/31/2007
$68,870
Serve as Deputy Director of Southern California Earthquake Center and Chair of the Planning Committee.

Archuleta
University of Southern California
075639-B ARP23
SCEC Strong Motion Database
02/01/02-01/31/07
$29,999
By this proposal we are requesting funding to continue development of the COSMOS Strong-Motion Virtual Data Center – (COSMOS VDC) – an unrestricted, web-based, interactive strong ground-motion data resource for practicing earthquake engineers, emergency response and recovery agencies and officials, researchers, and other earthquake professionals. The urgent need for effective and efficient access to strong-motion data has been well documented. Through the foresight of the agencies that have deployed and operate strong-motion networks there now exists an abundance of data. With the increasing deployment of digital recorders with high dynamic range such as TRINET, ANSS, and KNET, we can expect a continuing increase in the rate of data recorded. However, the full impact of the strong-motion data on public safety in earthquakes depends on their accessibility to the engineers, seismologists, and other users. With the basic goal of providing practicing earthquake professionals and public officials efficient, routine access to strong motion data as part of their practices, COSMOS has developed the VDC (http://db.cosmos-eq.org/).

The natural venue for this access is through the World Wide Web, which provides the means to retrieve data from any type of computer, view and copy plots and maps to the user's computer, etc. The universality of the Web allows equal access to all of the engineering and seismological communities, to large companies as well as university consortia. The VDC allows the user to search for and select the data most appropriate for a particular project or application, based on the individual user's needs. The VDC is the only strong-motion data center that is attempting to provide access to all strong-motion data on-line.

Archuleta
University of Southern California
0100810 ARP33
Implementation of SCEC Research for Seismic Risk Reduction
02/01/02-01/31/07
$40,000

We will use a stochastic process to approximate the physical process of rupture propagation and slip on a fault plane. The integrated characteristics of modeling source process are constrained by the Brune's w^{-2} source model. The details of the kinematic source model are not prescribed in advance. This stochastic modeling of the extended source process reflects, to a certain extent, the heterogeneity and uncertainty of the source process.

To simulate the kinematic rupture we divide the fault of the mainshock into subevents; each subevent represents a point source with parameters consisting of the local slip amplitude, rupture velocity, and rise time. In order to allow for our inadequate *a priori* knowledge we describe these parameters as random variables with probability distribution functions that are bound by estimates of the parameters based on past earthquakes. For periods longer than one second we will validate our approach with data from the Northridge earthquake and the latest version of the SCEC 3D velocity model.

The theoretical Green's functions and the synthetic ground motions are calculated, at low-frequencies (£1 Hz) by a 3D viscoelastic finite difference (FD) algorithm of Liu and Archuleta (2002), and at high-frequencies by a FK code based on layered structure (Zhu and Rivera, 2001). The choice of a crossover frequency at 1 Hz is due to our insufficient knowledge of the detailed 3D structure. This code includes a new absorbing boundary condition and coarse-grained attenuation (Liu and Archuleta, 1999b). It can simulate frequency-dependent or constant *Q* in the time domain. Another desirable feature of the code is that it implements a grid with variable spacing that allows for including near-surface low velocities.

Besides the kinematic modeling the extend source process, the other major consideration in the calculation of broadband ground motions is the generation of Green's functions. We will generate the site specific Green's functions used in the representation summation by convolving theoretical Green's functions with site-specific scattering functions,

Here, theoretical Green's functions g_{theory} are computed numerically from a 1D and/or 3D velocity model. In this case, the scattering functions h_{site} defined here are for correcting the difference between wave propagation in the true Earth medium and an assumed velocity model. Observed records of small earthquakes include the propagation effects between the source and the receiver. Assuming that the synthetic records are known, the site-specific scattering functions at a station is given by

where, $H_{site}(w)$ is Fourier transform of $h_{site}(t)$; $o_s(w)$ and $u_s(w)$ are the spectra of the observed and synthetic ground motion of the small earthquake. We choose small earthquakes with M 3~4, because their records have sufficient signal-to-noise ratio within a wide range of frequencies.

For the Puente Hills hypothetical earthquake, we can produce an arbitrarily large set of scenario source processes and corresponding ground motion time series. We will use the method of Lavallee and Archuleta (2003) to generate statistically equivalent slip distributions for the Puente Hills event.

Archuleta (ARP39)
University of Southern California
SCEC3 Participation: Hot Faults-Feedbacks in the Earthquake Process
02/01/07-01/31/09
$15,000

Laboratory and old observations suggest that velocity strengthening behavior is predominant during early deformation stages of fault zone evolution, leading to powerlaw-like Gutenberg Richter (GR) statistics, whereas localized, mature faults exhibit velocity weakening mechanisms, and characteristic-like events (CE) dominate the seismic response. A number of numerical studies with a variety of model implementations investigated parameter settings producing frequency-size statistics that correspond to the two end-member cases (GR-CE). Almost exclusively, the governing parameters in these studies are kept constant during single experiments. Laboratory data suggest an evolution of governing frictional properties with (cumulative) o set, sliding velocity, and strain. However, analytical expression of the feedbacks between them and the respective frictional parameters have not yet been derived. To explore the implications of these feedback mechanisms on seismicity evolution we thus have to parameterize the observations reported in the literature. These relationships will be used in a numerically efficient 1D BK type nearest neighbor model governed by a simple static/dynamic friction law to investigate seismicity patterns that correspond to these feedback mechanisms. First results using a linear time- or strain-rate-dependent `wear' effect on the frictional weakening parameter indicate a rather sharp transition in temporal seismicity evolution from power-law- to CE-like frequency size distribution. The associated transition from immature, disorganized configurations towards more regular, organized structures will be analyzed from the viewpoint of the \Highly Optimized Tolerance" (HOT) concept. HOT focuses on feedback mechanisms responsible for system evolution and an increased vulnerability to perturbations, resulting in an respective increased probability of large, devastating events. Because the specific organization or composition of the systems' constituents play a major role in understanding a system's performance, HOT makes different implications on the predictability of largest events compared to the criticality concept. As a consequence of the difference between requested and granted funding, we will not perform complementary dynamic rupture simulations.

Archuleta
University of Southern California
075639-A ARP35
SCEC2 Participation: Analyzing Nonlinear Site Response with Data From K-NET and KiK-NET
02/01/02-01/31/07
$20,000
Many have tried to find field data to quantify and understand nonlinear soil behavior. To isolate local site effects, the transfer function of seismic waves in soil layers has to be estimated by calculating the spectral ratio between the motion at the surface and the underlying soil layers for both strong and weak motion. For example, Darragh and Shakal (1991) observed an amplification reduction at the Treasure Island soft soil site in San Francisco; Beresnev and Wen (1996) reported a decrease of amplification factors for the array data in the Lotung Valley (Taiwan). Similar reductions have been observed at different Japanese sites including the Port Island site (e.g. Satoh *et al.*, 1997, Aguirre and Irikura, 1997). On the other hand, Darragh and Shakal (1991) also reported a quasi-linear behavior for a stiff soil site for a wide range of PGA?0.006 g to 0.43g. Clearly there is a need to define thresholds for the onset of nonlinearity (e.g.,

Idriss, 1990) and the maximum strong motion amplification factors that depend on the nature and thickness of soil deposits (Field *et al*., 1998).

Because of these difficulties, the most effective means for quantifying the modification in ground motion induced by soil sediments is to record the motion directly in boreholes that penetrate these layers. Using records on vertical arrays, one can separate the site from source and path effects and therefore clearly identify the nonlinear behavior and changes of the soil physical properties during shaking (e.g. Seed and Idriss, 1970; Zeghal and Elgamal, 1994; Zorapapel and Vucetic, 1994; Aguirre and Irikura, 1997; Satoh *et al*., 2001). Over the last thirty years, there has been a sustained effort to compile strong motion data from boreholes worldwide in order to develop a statistical relation between the spectral acceleration downhole and those at the surface in order to quantify the acceleration level at which nonlinear effects begin (e.g. Idriss, 1990). Importantly, such relations may be used to account for nonlinear effects in probabilistic seismic hazard scenarios (Tsai, 2000; Ni *et al*., 2000; Field , 2000; Steidl, 2000).

The extra dimension is that the Miyagi-Oki earthquakes had many aftershocks that were recorded at the same sites. With KiK-net sites having both up-hole and down-hole recordings, we can determine nonlinear parameters that give the best fit between synthetics and surface recordings. These parameters will be used in simulations for nearby K-NET recordings that have similar velocity/density depth logs. There are two natural benefits to this approach. First, we can further validate the NOAHW (Hartzell *et al*., 2004; Bonilla *et al*., 2005) code using real data, i.e., computing synthetics based on recorded borehole and surface accelerograms. Second, we can determine the range of nonlinear parameters for given velocity/density profiles. This will allow us to extend NOAHW's use to sites for which we have only a velocity/density profile. Of course, we do not expect as good a fit as one might get where a borehole record exists. However, this is the more general case, i.e., at most accelerograph sites one could expect at best a single strong motion recording, more likely only weak motion will exist.

One of the most critical aspects for mitigating the damage from earthquakes is knowing in advance how strong the shaking will be. There are many elements, e.g., source description, structural model, wave propagation, necessary to make reliable predictions on the ground motion in the event of an earthquake. Given that most metropolitan areas in Southern California (and around the world) are built on sediments, there is a high probability that the sediments will respond nonlinearly to the large amplitude seismic waves. Exactly how severe that response will be, even on average, is largely unknown. In some cases, the nonlinear response may produce the maximum acceleration (Archuleta, 1998); in others, it may significantly reduce peak acceleration (e.g., Darragh and Shakal, 1991). In the overall strategy for computing ground motion from future earthquakes that accounts for each element from source to site, the final stage must include nonlinear response Archuleta *et al*., (2003). Hartzell *et al.* (2004) have clearly demonstrated the importance of using a fully nonlinear code for this final, critical stage. However, they had only a limited data set, Nisqually, with which to validate NOAHW. The issue is not so much if the NOAHW can simulate the observed ground motion given an observed input, but how does one extrapolate the effect of nonlinearity from one site to another for the same input if only the geotechnical logs or local geological conditions are known. 4

We need to know how much variation in the nonlinear response we can anticipate. It is critical that we not under predict the ground motion. We cannot wait for the next earthquake in the US to analyze nonlinear ground motion. With the data from from the observed data of the 2003 (Mw 7.0) and 2005 (Mw 7.2) Miyagi-Oki earthquakes, we can verify the use of NOAHW and can simulate recorded motion where are only information is the geotechnical log of velocity and density at the site. This analysis will provide a basis for computing realistic ground motion from large earthquake's fundamental goal of the NEHRP.

Archuleta
University of Southern California
075639-A ARP22
Radiated Seismic Energy From Dynamic Faulting Models
02/01/04-1/31/07
$15,000
We propose to compute the seismic radiated energy for the 1994 Northridge earthquake. First we will determine the initial stresses from the slip distribution (Figure 1) using the method of Bouchon (1997). From the stress distribution we will derive a spatially heterogeneous initial stress and yield stress. The sliding friction stress will be fixed. From this distribution of stresses and in concert with a slip weakening friction law we will dynamically rupture the fault. The static stress drop will allow the computation of the elastostatic work available. This work is partitioned into work spent during fracture (fracture energy and relaxation) and work radiated as seismic energy. We will compute the radiated seismic energy as we have done for the 1979 Imperial Valley earthquake. Unlike Imperial Valley, the Northridge earthquake has teleseismic estimates of seismic energy. Thus we can compare not only the relative amount of energy between strike-slip and thrust, we can compare directly with teleseismic estimates of radiated energy. We will limit the number of computations for Northridge. We will not be able to generate our own teleseismic waveforms that would confirm unequivocally that the energy radiated from the fault, the teleseismic energy and the spatial distribution of energy on the focal sphere are all consistent.

Archuleta
University of Southern California
075639-AC ARP32
SCEC2 Participation: Inversion of Seismic and Geodetic Data from the 2004 Parkfield Earthquake
02/01/02-1/31/07
$30,000
The Parkfield data, along with the 3D velocity structure, provide a golden opportunity to examine the resolution of inversions. We propose to invert the Parkfield data using a global nonlinear inversion method (Liu and Archuleta, 2004). Rather than simply throwing all the data into one large problem, we want to examine how using subsets of the data influence the results. In particular, we want to examine how selecting different stations for inversion produce a faulting model. Using that faulting model we will predict the ground motion at the stations not used in the inversion. With the same objective function we will compute the misfit at each station and compare with the misfit at nearby stations that were used in the inversion. We have done this for the 1999 Chi Chi earthquake and found that the predicted stations had about a 30% increase in the misfit. There will be multiple inversions with different data sets all with about the same geographic distribution and same number of stations. With this we can derive a mean value and standard deviation for each kinematic parameter for each subfault. We will follow this by inverting all of the data to find a faulting model (call it FM-Total). How do the kinematic parameters of FM-Total compare with the mean value computed from multiple data sets? A related issue is whether the stations that extend perpendicular to the fault provide more control on the inversion than those that are parallel to the fault (Olson and Anderson, 1988). We will try a second approach is to examine when adding more data does not improve the fit. We start with ~20 stations for the inversion and keep increasing the number of stations in groups of 5 until the misfit between for the limited data is comparable to the misfit for FM-Total. This will be done several times with different starting groups of 20 stations, in case the initial distribution affects the conversion rate. We will also examine the difference between 1D and 3D velocity

models and the difference in the ground motion if the 3D model has a distinct contrast at the fault. Thurber *et al.* (2003) provide a 3D structure for the P wave and a Vp/Vs ratio to derive the S wave velocity.

Archuleta
University of Southern California
075639-AC ARP28
A Collaborative Project: 3D Rupture Dynamics, Validation of the Numerical Simulation Method
02/01/02-1/31/07
$55,000
Rupture dynamics modelers who consider the physics of earthquakes use a range of computational methods to simulate earthquake behavior. These methods range from finite-difference to finite-element, to spectral element, to boundary integral techniques. Although there have been a few small comparisons of two computer codes, for a limited range of test cases, until now, there has never been a concerted effort to fully examine the range of results being produced by these computer simulations of rupture dynamics. Since much of what we think that we know about earthquake physics behavior is the result of integrating actual seismic data with our rupture simulations, it would be important to know if our interpretations of earthquake source physics are self-consistent. For example, if person Y uses her computer code to interpret the behavior of the 1992 Mw7.3 Landers earthquake, and person Z uses his computer program to interpret the same earthquake, hopefully they should come to the same conclusions. However, if the two computer programs work differently, then they may well not agree, and earthquake source physics will remain a confusing science.

It is clearly necessary to compare the results of the various computer programs being used and to insure that they are producing the same results when implementing the same assumptions. For example, the same synthetic seismograms at a supposed earthquake's epicenter should be produced, irrespective of the computer program used to model the rupture dynamics, if all of these computer programs assumed the same fault geometry, material properties, and rheological behavior/friction.

When this code validation exercise is completed to our satisfaction, the computer programs used for simulating earthquake rupture dynamics will be brought into the greater community, including the SCEC CME, to be used with our experts' seal of approval. These computer programs will be able to fit nicely into Pathway 3 of the SCEC ITR, as a tool for generating scenario earthquakes and ground motions. This tool is also of interest to other groups, such as the current Pacific Earthquake Engineering Research Center (PEER) Next Generation Attenuation (NGA) project, and the SCEC Implementation Interface. It is also an integral component of our linkage with the SCEC Ground Motions and SHA Focus Groups and, with the SCEC Fault Systems Focus Group. For the latter, we need to link earthquake rupture dynamics (a.k.a. what happened during the earthquake) to longer-term fault behavior (a.k.a. what happens after the earthquake, until the next event).

The 2004 rupture dynamics workshop proposal was submitted to only fund travel to the participatory SCEC 1-day code validation workshop. No graduate student, postdoc or PI salaries are covered for the people doing the work, the modelers. If we wish our modelers to continue their contributions to this effort, we need some salary funding. This collaborative proposal is our salary request.

Archuleta
Steidl

University of Southern California
075639-L SJP06
SCEC Borehole Instrumentation Program
02/01/02-1/31/07
$20,000
The PI's maintain long-term research programs for analysis of borehole data. The salary support provided here (1.2 man months) will be used to continue the field efforts in support of the data gathering goals of SCEC, and to begin integrating the SCEC borehole data into the NEES data repository to facilitate increased collaboration and interaction with the engineering community. We also plan continued use of the data in site response analysis, dynamic simulation of nonlinear soil behavior, and estimation of path and source parameters from borehole data. Much of this effort, while funded through other resources, is directly related to the short- and long-term goals of the Center in the ground motions, earthquake source physics, and seismic hazard focus groups.

Implementation Interface and NEES Collaboration:

The George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) program is the NSF Engineering Directorates MRE&FC project that consists of 15 equipment sites for earthquake engineering research, all connected through the NEESgrid cyber infrastructure. One of these 15 NEES equipment sites is operated by the PI (JHS). This NEES project is to add two southern California engineering seismology downhole and structural array test sites into the NEES equipment portfolio and is on schedule for a September 30, 2004 completion. Starting in October, 2004, the PI (JHS) will maintain the permanently instrumented field site program for the NEES operations and maintenance phase, which is scheduled from 2004 to 2014. The PI's will continue to work towards increased collaboration and interaction with our engineering colleagues, and begin the task of integrating the borehole data from SCEC and NEES sites.

Archuleta
University of Southern California
075639-X ARP29
Quantifying the Variability in Linear Site Response
02/01/02-1/31/07
$20,000
Invert for frequency-dependent site amplification for all 29 earthquakes including those that were previously determined. We will vary our assumption as to the reference site and use an average of rock sites as well as an average of the deep borehole sites?KZ08, NS05 and TR10 which have the deepest accelerometers and with a well-predicted response based on borehole logs (Tsuboi *et al.*, 2001). We want to establish the most stable representation of the amplification. We will group the data according to the depth of the earthquake in order to separate Benioff events from shallow crustal events. The predicted spectrum is based on inverting for the seismic moment, corner frequency and frequency dependent Q for the path. In fact the path has almost no frequency dependence, ~f0.05. Having the source and path effects, the site response at the surface stations is a simple deconvolution: basically divide the observed spectrum by the predicted. Using all 21 deep events we can then average the site response to determine a mean site response for all 150 stations.

We will compute the mean and standard deviation of ground motion parameters: CAV, Arias intensity, spectral intensity, PGA, PGV, duration, dominant frequency for all events and all records. Having determined the ground motion parameters and site amplification we will correlate these with the basin depth, closest distance to the basin edge, Vs30 and local site geology. Naturally we will examine other variables such as depth the source, azimuth as well as PGA or PGV.

We have developed a nonlinear inversion method that provides a means of solving for the source parameters (seismic moment and corner frequency) and the frequency dependent attenuation in the path. By iteratively solving for the source, path and borehole response we can determine the source spectrum. The source spectrum is deconvolved from the recorded surface spectra giving a surface site response. The site response is averaged over events to give an average site response. This mean site response can now be regressed against other parameters such as CAV, SI, PGV, PGA, Vs30, etc. for separation spacing of 100 m to 20 km. We will limit ourselves to the data recorded prior to 2003. New data will not be incorporated into the analysis. Our correlations with basin depth and distance to basin edge will be limited to the variables PGV, PGA and CAV.

Archuleta
University of Southern California
113697 ARP36
Improving Methods For The Prediction of Broadband Time Histories
01/11/06-9/30/07
$35,000
This proposal will focus on two related topics: 1) refinement of our approach for the prediction of near-field broadband ground motion time histories, and 2) participation in the NSF and Yucca Mountain projects, where validated broadband prediction methods are used to compute ground motions.

We propose improving our predictions for a range of broadband strong ground motion that capture the effects of *i*) a rupture on a finite fault, *ii*) the complexity of the three dimensional Earth model and *iii*) local site conditions.

We will use the kinematic source model and a three-dimensional Earth model to calculate synthetic ground motions for frequencies up to one to two Hertz. The 3D model incorporates the geometry of the geology in the area, including the deep basin structures. We also compute ground motions with the frequency up to 15-20 Hz using a 1D model where the travel times are consistent with the 3D model.

Archuleta
University of Southern California
120044 ARP38
SCEC3 Participation: Rupture Nucleation and the Evolution of dc
02/01/07-01/31/09
$23,000
The first year is exploratory research. There is no verified approach that is certain to lead to a definitive answer though Andrews (2004) has given two plausible suggestions for how to start. However, unless we solve this problem for heterogeneous stress distributions, we will be extremely limited in the types of problems for which we can do dynamic simulations, i.e, we will have to specify *a priori* the size (seismic moment) of the event.

Our first steps will be to generate a limited suite of heterogeneous stress distributions for a fault with a large area. We need different realizations to be sure that our results are not biased by the initial starting conditions. These will serve as the basis of several numerical experiments. We will uniformly increase the shear stress over the fault until a point (or collection of points) on the fault reaches the peak stress. Then we will allow the fault to fail at these points by following a slip weakening friction law that has a variable. Our initial assumption is that is proportional to the area that is being swept out, i.e., instantaneous seismic moment. We will also try relations that will reproduce the general shape in Figure 1. It should be noted that Abercrombie and Rice (2005) have a variable length scale, which is possible because each event is treated as isolated from the other. They did not consider the evolution of the slip weakening as a rupture starts small and grows into a much larger event. Moreover, the stress drop is variable in their model with the larger events having more complete stress drops. This suggests another possible scaling of with size. If the stress drop or apparent stress is nearly a constant, this suggests that the slip scales with a length scale that may be related to a distance (one possibility is the rms value of distance to the rupture front by sampling the distance over a sweep over all azimuths from the hypocenter) that the rupture front has moved from the hypocenter. There is likely to be a limiting value to because as the rupture starts to sweep over the full width of the fault there will be a finite patch of the fault that is participating.

The basic question that we want to answer is how do we scale as the rupture evolves from a small region around the hypocenter to a larger region that involves the whole fault when the stress is heterogeneous. In such a case, the way in which is defined may depend on the correlation length of the stress.

Archuleta
University of Southern California
120044 ARP37
SCEC3 Participation: Prediction of Broadband Time Histories
02/01/07-01/31/09
$25,000
We will continue to improve and further validate this new method for predicting broadband ground motion. We propose 3 tasks:

Improve realization of high frequency radiation pattern. Extend the correlation of slip and average rupture velocity to a correlation of slip and local rupture velocity.

1) Validate using data from the 1992 Landers earthquake. Compute multiple scenarios to get a range of ground motion. Consider where the actual event lies within the range of models?

2) Implement the method into the broadband simulation platform.

We will work on refinement of our method. We have taken the first step at improving the realization of the high frequency radiation pattern by randomizing the incident azimuth (Fig. 1), but more testing will be necessary. Furthermore, instead of using a spatial correlation between average rupture velocity and slip amplitude we will implement a correlation between local rupture velocity and slip amplitude, as observed in dynamic modeling (Day, 1982; Oglesby and Day, 2002). This will improve our rupture model generator, especially when modeling faults with a large aspect ratio, e.g., 1857, 1906.

A key ingredient is the sensitivity of the bias and error to the input parameters and the correlation among the parameters. By further validation of the method against data from the Landers earthquake we intend to explore this sensitivity through multiple scenarios. In our approach we do not assume that we know the slip distribution. We only know the input parameters—moment, fault plane geometry, effective time (shortest dimension of fault divided by an average rupture velocity) and hypocenter. In essence, each actual earthquake is only one realization of what might have happened if all that we knew in advance that a certain magnitude earthquake would occur on a given fault. The multiple scenarios are necessary to understand the full range of ground motion as well as knowing if the data from a particular event is around the mean or far from it.

The implementation of the method in the broadband simulation platform will enable researchers who have not worked with the development of the code to execute it. Because the code is written in a modular way, it is possible to use our modules in combination with modules from other groups, for example, using our rupture model generator and the high frequency realization of another group.

Carlson
Burbank
University of Southern California
075639-A CXP01
SCEC2 Participation: Implications of Rapid Velocity Weakening and Healing Mechanisms for Rupture Dynamics and Ground Motion
02/01/02-01/31/07
$25,000
Friction remains difficult to determine in seismological settings, though numerous experiments, theoretical studies, and numerical studies suggest mechanisms that may arise in the earth. This project investigates the consequences of these friction mechanisms and the corresponding constitutive laws in the context of three dimensional, continuum, dynamic rupture models, to determine how different friction laws impact dynamic propagation, rupture speed, complexity, and ground motion. This builds on recent advances in Carlson's group on developing constitutive laws for granular materials (Lemaitre, 2002; Lemaitre and Carlson, 2004; Lois, Lemaitre, and Carlson, in press) as well as dynamic modeling (Dunham, Favreau, Carlson, 2003), and effects of dynamics on ground motion (Page, Dunham, and Carlson, in press). The proposed work incorporates laboratory observations of rapid velocity weakening and strengthening mechanisms in a three dimensional dynamic rupture simulation codes which have been tested by members of Carlson's group (Eric Dunham) in SCEC numerical code validation workshops.

The remainder of the technical description is divided into two sections. Section II summarizes the friction mechanisms and constitutive laws. Section III describes how these mechanisms will be incorporated in models for dynamic rupture and ground motion, along with features which will be investigated. The project addresses SCEC research objectives in Fault and Rock Mechanics, Fault Systems, and Earthquake Source Physics. In Fault and Rock Mechanics, use of constitutive laws -- especially those that feature dynamic weakening -- in simulations provide critical feedback for experiments on rock mechanics and friction. Once basic behaviors of the friction laws have been studied, simulations will focus on consequences for Earthquake Source Physics and Fault Systems to determine which constitutive laws and mechanisms reliably reproduce observed fault dynamics and complexity. Rapid velocity weakening and strengthening are expected to play a significant role in dynamic rupture propagation, complexity of the residual stress field, and the total energy released as radiation. Accurate predictions of the dynamics are essential to understanding how future seismic events may impact Southern California.

Carlson
University of Southern California
120044 CXP02

SCEC3 Participation: Rapid Weakening due to Fault Gouge Localization: Constitutive Laws, Rupture Dynamics and Ground Motion
02/01/07-01/31/09
$23,000
The project addresses short-term SCEC research objectives in Fault and Rock Mechanics and Ground Motion (A8, A10, and B1) by developing physically-based constitutive laws featuring rapid velocity weakening, and elucidating their impact on rupture dynamics, faulting energy balance, and ground motion away from the fault. Gaining a better physical understanding of friction models will aid long-term SCEC objective in constraining Earthquake Source Physics, and will better inform models of fault system dynamics. Accurate predictions of the dynamics of both single ruptures and networks of faults are essential to understanding how future seismic events may impact Southern California.

Revised Statement of Work: We hope to be able to fulfill the objectives in the original proposal. The decrease in funds will impact salaries and travel, which we hope to be able to make up from other sources on this funding cycle.

Constitutive Laws

- Analyze the dynamics of a physics-based, microscopic model for fault gouge that localizes under shear strain
- Develop a novel constitutive law based on this analysis that exhibits velocity weakening
- Compare the stability and dynamics of this new constitutive law to others, including Lemaitre's boundary lubrication model and the Dieterich Ruina friction law

Dynamic Rupture Modeling

- Test new friction laws developed from microscopic models in spontaneous, continuum dynamic rupture calculations to explore how they weaken with slip and velocity, their rupture mode (crack vs. pulse), and the associated event complexity of ruptures.
- Study how new friction laws balance stored elastic energy between fracture, frictional dissipation, and radiated seismic energy.
- Model high frequency ground motion produced by improved earthquake source models, and assess how such models can improve source models used in physics-based hazard analysis.

Carlson
University of Southern California
120044 CXP03
SCEC3 Participation: Resolution of Kinematic Source Models
02/01/07-1/31/09
$15,000
This project addresses uncertainty in the inverse earthquake problem. Using methods from robust control theory [*Dullerus and Paganini*, 2005], this project develops bounds on source characteristics by defining and solving a series of optimization problems which maximize the information extracted from seismic inversions and determine which features are well-constrained by the data. Quantifying uncertainty in kinematic inversions is necessary in order to interpret the variability and features seen in source models. While kinematic inversions provide direct images of the seismic source, the robust features of these images are not well known. A thorough treatment of the consequences of uncertain models and statistical

correlations in seismic inversions is necessary in order to characterize the inherent variability of the seismic process.

This work fits SCEC3 objectives A4, A10, and B1. Objective A4 calls for statistical analysis and mapping of source parameters with an emphasis on their relation to known faults. Our project focuses on better understanding the statistical correlations between possible models of slip (and therefore stress change) on the Parkfield segment of the San Andreas Fault. Also, Objective A10 describes the development of statistical descriptions of heterogeneities over multiple earthquake cycles. Indeed, the Parkfield segment is ideal for studying the earthquake cycle, as data from multiple moderately sized earthquakes have been recorded there. It is necessary to know the error in inversion methods in order to determine to what extent the Parkfield earthquake are "characteristic". Finally, Objective B1 asks for the development of kinematic rupture scenarios consistent with observations. Our project seeks to better describe this large solution space that is consistent with observations (as opposed to selecting only a few arbitrary models from this space).

Revised Statement of Work. This project will accomplish the following tasks:

a) Resolution analysis of the Parkfield GPS data will be extended to the fully nonlinear inversion of the strong motion data. b) Synthetic tests will be used to test how well the linearized resolution bounds apply to the nonlinear inversion. In addition to helping us better constrain the true error bounds of the nonlinear inversion, this will gauge how strongly the nonlinear constraints reduce the model space. c) We will investigate how well bootstrapping performs in fully nonlinear inversions. In previous work we have found that bootstrapping underestimates the uncertainty in underdetermined linear problems, but it is not clear in what way a nonlinear search algorithm will change this result. d) We will identify biases that can result due to the inversion procedure itself. For example, the generalized inverse approach can generate apparent structure that is not real due to non-diagonal terms in the resolution matrix.

Keller
Burbank
University of Southern California
075639-A KEP01
SCEC2 Participation: Seismic Hazards Associated with Active Deformation Within the Camarillo Fold Belt, Western Transverse Ranges, Southern California
02/01/02-01/31/07
$25,000
The Camarillo fold belt (CFB) in the western Transverse Ranges is composed of numerous active south-verging folds and reverse faults that pose an unknown hazard to nearly one million people living in the cities of Ventura, Camarillo, Thousand Oaks, and Oxnard as well as north and east in the San Fernando, Simi, and Santa Clara River Valleys. Although numerous consulting reports have been completed on some of the known faults, the CFB is the last remaining fold belt between the Los Angeles fold belt and the Santa Barbara fold belt that has not been studied as a unit for the purpose of evaluating potential seismic hazard.

A suite of growing east-west-trending anticlines and faults in the CFB deform late Pleistocene to Holocene sediments including those of the Oxnard Plain (delta of the Santa Clara River) with prominent fold and fault scarps. These folds are likely underlain by reverse faults that have controlled their growth and present a clear seismic hazard to the area, which is undergoing very rapid urbanization. The belt also contains the active and nearly unstudied Simi fault with left-oblique displacement. This proposal seeks to assess the potential seismic hazard presented by the CFB through identification of seismic sources, quantification of potential rates of deformation, and initial evaluation of likely earthquakes and their magnitudes that can be expected in the future. Whereas several previous studies have focused on individual structures in the CFB (Blake and Ploessel, 1991; Shlemon and Simmons, 1995; Hitchcock et al., 1998; Treiman, 1998; 1999), no thorough tectonic synthesis has been completed. Furthermore, with the exception of earlier limited evaluations (Jakes, 1979; Hanson, 1981) scant attention has been paid to the interactions among multiple, synchronously active structures. This initial SCEC project is designed to generate such a synthesis and evaluate seismic hazards. Subsequent research will focus on numerical ages and rates of Holocene and late Pleistocene deformation in the CFB and excavation of fault trenches across specific faults such as the Simi fault.

Lavallee (LDP04)
University of Southern California
SCEC3 Participation: Random Properties of Slip Spatial Heterogeneity for the 1999 Izmit Earthquake
02/01/07-01/31/09
$22,000
In this proposal we proposed first to compute the random properties of measurements of slip for the 1999 Izmit and Durze earthquakes and second to develop random model for the computed slip inversions of the 1999 Izmit earthquake. Since the funding for this proposal has been reduced by almost 50%, we propose in this revised project to focus on the first task of the proposal. The second tasks will be undertaken granted that time is available or that other sources of funding allow the completing of this investigation.

Lavallee
Burbank
University of Southern California
075639-AC LDP02
SCEC2 Participation: Coupling of the Random Properties of the Source and the Ground Motion for the 2004 Parkfield Earthquake
02/01/02-01/31/07
$20,000
In this revised project, priority will be given to the analysis of the slip spatial heterogeneities of the source models of the 2004 Parkfield earthquake computed by Dr. Ji (Caltech) and Dr. Liu (UCSB). In parallel to this study of fault heterogeneity, we will also investigate the statistical properties of ground motion recorded for this earthquake. We propose to compute the PDF of the peak ground acceleration (PGA) and to determine the probability law that best fit the PDF curve. The results of this analysis will be compared to the stochastic model of the slip spatial distribution of the 2004 Parkfield earthquake. Other investigations discussed in Section 3 of this proposal, will be undertaken granted that the tasks discussed above are completed in a period of time shorter than two months or that other sources of funding allowed to pursue and complete these investigations.

Regarding the panel summary, I would like to reply to this specific comment:
“The proposal would be strengthened if the PI could demonstrate higher level interactions with other SCEC researchers or groups. e.g., how this work might relate to planned activities in the Implementation Interface, Earthquake Physics or Ground Motions groups (beyond display of a poster at the Annual mtg.)”

During the period going from 02/01/04 to 01/31/06, I participated to three workshops sponsored by SCEC — Rupture Dynamics Workshop (Sept. 19, 2004), the SCEC Rupture Dynamics Code Validation Workshop (Nov. 8, 2004), and the Broadband Ground Motion Simulations (Jan. 28, 2005). Following a call to the SCEC community by Mark Benthien, to provide materials for the SCEC booth at the Fall AGU meeting, I provided a movie about rupture propagation under heterogeneous conditions. During the meeting, the movie was on display with other SCEC projects. I also produced a SCEC report and a Science Nugget (see http://www.scec.org/core/public/showNugget.php?entry=2118) regardless of the fact that my project didn't receive any SCEC funding for this period of time. Although I do agree that members of the SCEC community should make special effort to get involve in SCEC activities, I have two questions regarding the comment quoted above.

1. Do you think that the activities outlined above are "beyond display of a poster at the Annual mtg" (a poster that I am always pleased to discuss with members of the panel)?

2. How this level of participation actually compares to the records of colleagues who actually did get SCEC funding over the same period of time?

Lavallee
Burbank
University of Southern California
075639-AG LDP03
SCEC2 Participation: Stress Spatial Heterogeneity and its Effect on Earthquake Rupture
02/01/07-01/31/07
$30,000
In this project, we will proceed as discussed in the fourth section of the proposal. We will simulate rupture initiation and propagation under very heterogeneous conditions generated with a stochastic model of the pre-stress spatial distribution. Computation of the rupture propagation will be achieved using a 3D finite element (FE) code developed by S. Ma (UCSB). We will construct three banks of scenarios that essentially differ in the amount of correlation included in the pre-stress spatial distribution. We will study how the amount of correlation affects rupture velocity and directivity. We will pay special attention to directivity since this parameter has been identified as potentially more relevant in the panel summary of the SCEC Planning Committee. It will be a pleasure to work on this investigation in collaboration with Greg Beroza and Rob Graves. Additional investigations, discussed in the fourth Section of this proposal, will be undertaken granted that the tasks discussed above are completed in a period of time shorter than two and a half months or that additional sources of funding are found to pursue and complete these investigations.

Liu
Archuleta
Burbank
University of Southern California
075639-AC LDP04
SCEC2 Participation: Developing and Validating a Method for Prediction of Broadband Time Histories
02/01/02-01/31/07
$25,000

This proposal will focus on two related topics: 1) further developing and refining our approach for the prediction of near-filed broadband ground motion time histories, and 2) participating in the project, organized by SCEC Ground Motion Group and Implementation Interface Program, to validate and compare different prediction methods.

Prediction of realistic time history of ground motion from future earthquakes is essential to completely describe earthquake hazard, and as such it is a key component of the SCEC short-term objectives. While we cannot know the exact time of the next damaging earthquake, geologists, seismologists and geodesists have delineated faults that are capable of producing large magnitude earthquakes in urban areas. For example recent work by Shaw and others (2002) has spotlighted the Puente Hills thrust fault system that underlies the Los Angeles metropolitan area. This system is capable of producing earthquakes from M_W 6.5 to 7.1. If there were such an earthquake, what would the ground shaking be in the greater Los Angeles area? Which areas would experience the maximum shaking? How would the local geological conditions, or the depth of the Los Angeles basin its edges affect the ground motion. We propose predicting a range of broadband time histories of strong ground motion that capture the effects of *i*) a rupture on a finite fault, *ii*) the complexity of the three dimensional Earth model and *iii*) local site conditions.

A credible model of the complex source process is essential for the prediction of ground motion. Although efforts have been made to implement the dynamic modeling of extended source models to predict ground motions (Guatteri, *et al.*, 2003), high-frequency dynamic fault models are still quite difficult and computationally expensive. Although the computational limits can be overcome to some degree, our poor knowledge of stress on the fault, frictional properties, and the constitutive failure law make the problem difficult when attempting to construct broadband ground motion. Kinematic modeling remains as one of the best means to incorporate many aspects of physical models of the earthquake process while still being able to compute broadband strong ground motion. We have developed a technique for kinematic modeling of an extended earthquake source that is based on distribution functions for the slip amplitude, duration of slip (risetime) and rupture time. The complexity of the source process is represented by spatial distributions of randomized source parameters, but the integrated characteristics of these parameters will be constrained by the total moment (magnitude), radiated energy and the high-frequency decay of the spectral amplitudes in the source spectrum.

We will develop a technique to generate high-frequency Green's functions that combines both the Earth model and data obtained from small earthquakes recorded on the California Integrated Seismic Network (CISN). We use recordings of earthquakes with M 3~4 and one-dimensional approximations to the velocity structure to derive high-frequency (greater than 1 Hz) Green's functions that include site-specific local site conditions. The site-specific Green's functions are then convolved with suites of kinematic source models to generate time histories of high-frequency ground motion. We will use the kinematic source model and a three-dimensional Earth model to calculate synthetic ground motions for frequencies up to one to two Hertz. The 3D model incorporates the geometry of the geology in the area, including the deep basin structures. The high- and low-frequency synthetic ground motions are stitched together to form a broadband time histories of ground motions

Strong ground motions can induce non-linear soil response near the surface. The ground motions generated by our method will not account for the non-linear character of soils. However, the synthetic ground motion can be used to compute the nonlinear site response when the geotechnical information at the site is available. Before performing the validation, a synthetic time history is first deconvolved to the bedrock level using the geotechnical information. Then this bedrock time history is propagated to the surface using a 1D nonlinear wave propagation code (e.g., Bonilla *et al.*, 1998).

This proposed prediction approach would be validated under the project designed by SCEC Ground Motion Group and Implementation Interface Program. At same time we will estimate the modeling uncertainty generated from this approach.

Liu
University of Southern California
075639-P LPP03
Quantifying Uncertainty in Finite Fault Inversions
02/01/02-01/31/07
$20,000
In our original proposal we included the following statements of work: 1) estimate the uncertainty in the finite fault solution using the bootstrap method, 2) examine the effect of different objective functions on the finite fault inversion, 3) apply our approach to the data from the 1994 M 6.7 Northridge earthquake, 4) use a hybrid technology in the bootstrap process of analyzing the data. The bootstrap process would use the global inversion method (*Liu and Archuleta*, 2000) and the original data set to invert for a best source model. This solution is then chosen as starting model, and a linearized iterative inversion technique (*Hartzell,* 1989) would be applied to invert bootstrap data samples.

With the modified budget we will do the proposed work with a significant modification. We will not adapt the bootstrap method to the linearized iterative inversion technique of Hartzell (1989). Instead we still use our global inversion method (*Liu and Archuleta*, 2000) in the whole bootstrap process. This adjustment will not affect the basic objectives of the proposal. It reduces the time for the researcher supported by this proposal; however, the computer time to complete the work will increase significantly which may limit the number of parameter studies that can be done.

Liu
University of Southern California
075639-C LPP02
Resolution and Stability Analysis of Finite Fault Inversions
02/01/02-01/31/07
$20,000
Since the original inversions of strong motion data by *Trifunac and Udwadia* (1974), there have been a vast array of inversion methods applied to near-source ground motion records. Correctly determining the kinematics parameters of the rupture process is fundamental to our understanding of earthquake physics. The kinematic parameters obtained from an inversion can be used to infer the stress drop distribution (e.g., *Mikumo and Miyatake*, 1995; *Bouchon*, 1997; *Day et al.*, 1998) that in turn can be used as the input for dynamic models (e.g., *Olsen et al*, 1997; *Nielsen and Olsen*, 2000; *Archuleta and Favreau*, 2001). The kinematic parameters have been used to infer scaling properties (e.g., *Somerville et al.*, 1999; *Mai and Beroza*, 2000) and as input to finite difference codes in an attempt to determine frictional parameters (e.g., *Ide and Takeo*, 1997). Of course, the spatial and temporal distribution of source parameters is critical in forward modeling of ground motion. As such the inversions serve as a baseline for the range of parameters that are plausible in predicting ground motions for engineering design purposes.

Methods for inverting the data usually require parameterization of the faulting process by dividing the finite fault into a grid of small cells or subfaults and approximating the ground motion at a given station by a linear sum of the synthetics originating from these subfaults. There is no criterion to decide how large a subfault should be. Several papers show that changes in the size of subfaults can have a significant effect on a finite-fault inversion (*Hartzell and Langer*, 1993; *Das and Suhadolc*, 1996). In a similar vein there is a wide range of objective functions that are to be minimized in the process of comparing synthetic time histories with the data. It is unclear how the choice of an objective function affects the inversion results. The rupture process on the fault is deduced through iteratively fitting the synthetic time histories to recordings (by use of the objective function). Obviously the solutions obtained from this inversion process will depend on the Green's functions because they are essential to the representation theorem used to compute synthetics that are compared to data. With the recent advent of efficient 3-D numerical wave propagation methods and improved knowledge about the crustal structure, it is now possible to invert for kinematic parameters of a finite fault using Green's functions computed from a 3-D structure. Do 3-D Green's functions improve the resolution of kinematic source parameters?

This proposal focuses on three elements of finite fault inversion methods: 1) influence of subfault size; 2) choice of objective function for minimizing the difference between synthetics and 3) effectiveness of 3-D Green's function in determining the kinematic parameters of faulting.

Niemi
University of Southern California
075639AA NPP02
Seismic Hazard Assessment of Urban, fault-Related Uplifts from Quantitative Geomorphology
02/01/02-01/31/07
$16,137
Comparison of thrust-bounded mountain ranges of similar lithology in southern California reveals that topographic relief above active thrust faults is broadly proportional to fault slip rate. For example, topographic relief across the Elysian–Repetto Hills (uplift rate 1 mm/yr) ranges from 100-300 m; conversely, the topographic relief across the Santa Susana Mountains (uplift rate 6 mm/yr) exceeds 1000 m. This project aims to quantify the relationship between topographic relief and fault slip rates in the Los Angeles and Ventura basins through the analysis of fluvial dissection of tectonically produced topography. This project applies a physically-based model linking stream-channel gradient to erosion rates to estimate rock uplift rates above active faults. This analysis will concentrate on youthful uplifts of Neogene sedimentary rocks for which the lifetime of topography (e.g., the relief divided by uplift rate) is of order 100-200 ka. Tectonic deformation rates over this time scale are directly applicable to seismic hazard assessment and complementary to paleoseismic studies of earthquake recurrence and geodetic studies of vertical deformation. Results from this study will be incorporated into the SCEC Community Geologic Vertical Motion Map. The rate and distribution of uplift determined from this data set will be calibrated against longer-term deformation patterns determined from structural geology and tectonic geomorphology studies of fault-related fold uplifts in southern California.

Active faulting within the urbanized areas of southern California includes shortening across numerous, cryptic, blind fault systems for which seismic hazard has proven difficult to quantify. Geologic mapping together with seismic and oil-well data have proven effective in defining many large-scale contractional faults and fault-related folds within the Los Angeles and Ventura basins (Yerkes et al., 1965; Davis et al., 1989; Wright, 1991; Huftile and Yeats, 1996; Schneider et al., 1996; Shaw and Suppe, 1996; Shaw and Shearer, 1999; Tsutsumi and Yeats, 1999). Although most of these contractional features have formed within the past 6 Myr, these data generally cannot define activity in the last 100,000 years, as is required to confirm seismic hazard. Geomorphic analysis of deformed terrace markers and Late Quaternary stratigraphy have been used effectively to define activity on some fault related folds (Bullard and Lettis, 1993; Mueller, 1997; Ponti et al., 1996; Oskin et al., 2000; Dolan et al., 2003). However, despite the presence of tectonically-produced topography in association with many fault-related folds in southern California, deformed Late Quaternary markers are not well-defined for the majority of these structures.

We propose to define and quantify seismic hazard from blind faults through analysis of eroded topography formed above active fault-related uplifts (Fig. 1). A new tool, developed in Arc/Info, combines the rapid acquisition of stream gradients and catchment size from high-resolution digital topography with a physically-based erosion-process model to measure the fluvial response to variable rock uplift rates. Previous workers have shown this method to be applicable to single stream profiles extracted from digital topography of the Siwalik Hills of Nepal (Kirby and Whipple, 2000) and the Santa Ynez Range of southern California (Duvall et al., 2002). The tool developed for this project permits rapid analysis of entire stream networks, rather than single stream profiles, providing a synoptic view of fluvial response to active topographic growth. Preliminary results acquired from a USGS 10-meter digital elevation model (DEM) (Figs. 2 and 3), demonstrate that we can calibrate and measure uplift rates using this technique. Spatial trends in these data support observations of differential structural growth and yield new insight into the relationship between topography and mapped geologic structures (Fig. 4).

The results of this study will significantly refine our understanding of how crustal shortening is distributed across southern California, and thus directly impact seismic hazard assessments. We will apply this method over a wide region of southern California where topography is developed within uniform, weak, and easily eroded Neogene sedimentary rocks. Topographic analysis and field measurements of stream channels above active structures with known uplift rates will be used to calibrate the model. Following calibration, these analyses will be extended into areas of unknown uplift rate. We have identified three critical areas (Fig.1) where this method can yield important new results on the distribution of seismic hazard from contractional fault related fold growth:

(1) The Puente and Coyote Hills (Fig. 1), which overlie the active Puente Hills thrust (Shaw and Shearer, 1999), are in detail comprised of numerous folds developed in Neogene strata (Yerkes et al., 1965). Because of a lack of dateable, deformed Late Quaternary deposits, activity remains to be demonstrated for most of these structures (Wright, 1991). Documentation of uplift rates here are especially desirable because the Puente Hills are centrally located within the urban area and lie at the up-dip projection of a major mid-crustal decollment imaged in the LARSE I seismic line (Fuis et al., 2001).

(2) The foothills of the Santa Ana mountains, in eastern Orange County (Fig. 1), contain uplifted exposures of Neogene sedimentary rocks (Vedder, 1975; Schoellhamer, et al. 1981). South of the Peralta Hills thrust (Wright, 1991), the generation of this topography is not well understood. A possible explanation for uplift is activity on the southern segment of the Lower Elysian Park ramp proposed by Shaw and Suppe (1996). Although the northern segment of this deep, transbasin fault system is demonstrated by Mueller (1997) to be inactive for the past 400 ka, activity on the southern segment has not been ruled out. The spatial distribution and magnitude of uplift will help to quantify the hazards posed by this large structure, capable of producing an Mw 7.5 earthquake.

(3) The western Ventura basin is traversed by numerous youthful fold structures with significant topographic expression (Fig. 3). Yeats (1977, 1987), Yeats et al., (1994), Yeats and Huftile (1995), and Huftile and Yeats (1996) have quantified long term deformation rates and fault geometry for the major structures in this region. However, Late Quaternary uplift rates have not been determined for most of these structures. The Ventura basin is identified as undergoing upwards of 1 cm/yr of contraction (Hager et al., 1999). Understanding of the distribution of this contraction as uplift over the suite of structures mapped in this region will significantly refine understanding of seismic hazard.

Niemi
University of Southern California
075639Z NNP01
Development and Integration of the SCEC Community Vertical Motion Map
02/01/02-01/31/07
$19,035
We propose to continue development of a community vertical motion map of southern California. There are abundant data on vertical motions that are not compiled into one useable source, and which are not likely to be compiled under the current Fault Activity Database (FAD) or Fault Information System (FIS) effort. In most cases, these data are in the form of dated marine terraces, river terraces, thermochronology, sediment accumulation rates, and other such information that record long-term rates of uplift and subsidence. The primary goals of this project will be to: 1) complete development of the database format and procedures such that it will faithfully represent geologic relationships that underpin vertical motion measurements; 2) compile all available information on vertical motions in southern California; and 3) developing a web-based access point to the vertical motion database; 4) collaborate with the Community Fault Model, Fault Activity Database, and the SCEC IT Program to develop a unified web-based map server for viewing, querying, and downloading data. It is anticipated that as a result of this compilation and integration effort, there will arise obvious areas where data are not available and where new data are desired. This will provide a platform from which to launch a larger initiative to NSF, probably in collaboration with SCEC and LLNL, to begin a systematic program of acquiring new cosmogenic dates on uplifted surfaces throughout southern California. The end result will be a well documented assessment of the long-term (105 year timescale) vertical motions that will provide a basis to assess hazards due to blind thrust sources, and compare to the secular GPS rates that will shortly be of sufficient resolution to be significant.

Olsen
University of Southern California
075639-Q OKP14
Estimation of LA Basin Seismic Wave Amplification Effects
02/01/02-01/31/07
$20,000
We propose to continue ongoing work comparing ground motion computed by prescribed and dynamic rupture propagation for dipping faults buried up to 5 km (*Gottschammer and Olsen*, 2001). We use a fourth-order finite-difference (FD) method and the mixed boundary condition with a rate- and slip-weakening friction law. The numerical grid is parallel to the fault plane with the free surface at an angle with respect to the numerical grid by introducing a vacuum layer. Preliminary results for a 45 degree dipping thrust fault suggest that inclusion of these effects increases the peak displacements and velocities above the fault significantly by including the increase in moment due to normal-stress effects at the free surface (see Fig 1. of Progress Report: How Can We Improve Ground Motion Estimates by Lessons Learned from Rupture Dynamics?). The results suggest that dynamic interaction with the free surface can significantly affect the ground motion for faults buried less than 1-3 km. We believe that the proposed research can help delineate the range of effects that may be expected in a realistic earthquake scenario.

We propose to continue the work by (*Gottschammer and Olsen*, 2001) by comparing prescribed and spontaneous dynamic rupture propagation on dipping thrust faults buried 0-5 km in half-space and realistically layered models, as well as ground motions on the free surface for frequencies less than 1 Hz.

The comparisons include dynamic simulations using a 3D FD method with rate-and-state friction on a planar fault in a realistically layered medium. In the continuation of the project proposed here we will test the effects of using more realistic heterogeneous dynamic rupture parameters, as well as variation of the stress level in the near-surface material. We will continue testing the findings that ground motions from buried faulting are consistently stronger than that from earthquakes having large surface slip (*Somerville*, 2000), for heterogeneous distributions of rupture parameters.

Olsen
University of Southern California
075639-R OKP15
Estimation of Dynamic Rupture Parameters
02/01/02-01/31/07
$15,000
We propose to continue to develop, implement and test a systematic inversion method to estimate rupture propagation and the underlying dynamic parameters for large historical earthquakes using the Neighborhood algorithm (NA). We will test the efficiency and limitations of the method on realistic fault models. The tests include estimating the number of parameters that can be reliably determined, the dependence of the initial model, of the control parameters of NA and selection of rupture parameters (i.e., stress, friction, or rupture energy), the need for constraints on the rupture parameters, and rate of convergence. We will implement ways of speeding up the convergence of the method, including 'early detection' of 'poor' models, for example those where rupture does not initiate. We will optimize the finite-difference forward modeling method in terms of RAM and cpu-time requirements. To achieve this goal, we plan to use the efficient Perfectly Matched Layers (PML) absorbing boundary conditions (*Marcinkovich and Olsen*, 2003).

We propose to examine in detail the constraints that near-fault strong motion records can provide for the slip-weakening distance (*Mikumo et al.*, 2003). In particular, we propose to investigate the resolution of D_c. We will estimate D_c from near-fault ground motions for the 1979 Imperial Valley and 2002 Denali earthquakes. We will examine the radius of influence from the fault on near-fault strong motion records in order to address the severity of the averaging process controlling the estimate of D_c. Finally, we propose to estimate the effect of different kinds of slip-weakening behavior on the resolution of the method.

Olsen
University of Southern California
075639-E OKP10
Direct Measurement of the Slip-Weakening Distance from Near-Fault Strong Motion Data
02/01/02-01/31/07
$20,000
The proposed research is inspired by the request from two different Focus Groups to analyze the nature of friction, in particular using information from radiated waves emitted by the earthquake rupture (Goals 3d and 4c). Here, we propose to investigate in detail to which extent one of the most important frictional parameters controlling earthquake rupture propagation, the slip-weakening distance D_c, may be estimated directly from near-fault strong motion records for steeply-dipping shear faults. Preliminary results using numerical dynamic rupture simulations in a slip-weakening model indicate that D_c can be estimated within an error of 50% as the slip displacement at the time of the peak slip-velocity T_{pv} from the near-field

fault-parallel component of ground motion. This technique may provide the only estimate of D_c independently of the fracture energy G, and therefore also an estimate of the strength drop using D_c and G. The method provides a very simple approach that could lead to significant progress in characterizing the friction of earthquake rupture.

Olsen
University of Southern California
075639-F OKP11
3D Ground Motion Simulation in Basins
02/01/02-01/31/07
$29,500
The project will foster the integration of 3D ground motion simulation methods and results into engineering applications. We will validate 3D simulation methods and apply them to complex geological structures, with emphasis on urban sedimentary basins. We propose a coordinated, multi-institutional investigation, with funding shared between the Pacific Earthquake Engineering (PEER) Center and the Southern California Earthquake Center (SCEC). The PEER and SCEC research components will be fully integrated, and the project will be structured to address the engineering and science requirements of both Centers. A companion proposal with the same title and team of investigators was submitted to SCEC in December 2001.

Olsen
University of Southern California
075639-G OKP12
Fully Three-Dimensional, Multi-Scale Waveform Tomography for the Los Angeles Basin
02/01/02-01/31/07
$10,000
We propose to conduct a 3D tomography study for the seismic velocities in the LA Basin and its immediate neighboring regions. The approach we take represents an improvement to the similar studies in three aspects. First, we use waveform-based measurements such that more information in seismic records can be utilized to provide better constraints (coverage) to the velocity structure. Second, we adopt accurate finite-difference method to compute sensitivity or Frechet kernels of the measurements so that 3D reference models can be accommodated without the need for high frequency or averaging approximations. Finally, we pursue the inversions in a multi-scale fashion, starting from lower frequency and inverting for larger-scale structures, and progress to higher frequencies and smaller-scale structures. This ensures that the linearity between data and structural parameters is better preserved at each step of the inversions.

Olsen
University of Southern California
075639-H OKP13
How Can We Improve Ground Motion Estimates by Lessons Learned from Rupture Dynamics?
02/01/02-01/31/07
$25,000
The proposed research is a priority within several SCEC focus groups. The Fault Systems Group asks for examination of the effects of fault (Goal 2f) and fault-zone (Goals 2a, g) complexities. In the Rupture Dynamics Group, goals include rupture branching (Goal 4e), normal-stress effects (Goal 4f), and rupture

behavior at step-overs (Goal 4h). The Wave Propagation Group requests analysis of near-fault ground motion and the effects on strong ground motion from energy trapped between the fault plane and the free surface for thrust fault. (Goal 5-4).

Here, we propose to address these issues to improve estimates of strong ground motion using significant advances recently obtained in dynamic rupture modeling. We will compare traditional prescribed (kinematic) and spontaneous dynamic rupture propagation and will report on differences for thrust faults with various dip angles and dynamic friction. We will examine the significance of fault curvature and bends on near-fault strong ground motion. Finally, we will examine to which extent broadband strong motion synthetics may be improved by including results from dynamic rupture modeling, such as the shape of the sliprate functions and variation in rise time.

Oskin
University of Southern California
075639-T OMP04
Implementation of the SCEC Community Vertical Motion Map
02/01/02-01/31/07
$10,000
This Geologic Vertical Motion Database (GVMD) and vertical motion map utility will be developed and maintained at the Institute for Crustal Studies at the University of California, Santa Barbara. Similar in organization to existing databases of fault geometry (CFM), fault activity (FAD), crustal motion (CMM) and seismic velocity (CVM), the GVMD and vertical motion map utility will be an on-line, maintained, and documented resource available to the scientific community.

N. Niemi and M. Oskin will each devote two months to completion and testing of the GVMD and vertical motion map utility. Niemi and Oskin are both geologists experienced with Arc/Info GIS and familiar with object-oriented programming languages and database-driven web applications. Niemi has been programming in ArcGIS for the past year full time as academic staff at the Massachusetts Institute of Technology. Population of the GVMD with available geologic data will take advantage of the variety of experience and resources available at the Institute for Crustal Studies at the University of California, Santa Barbara. C. Sorlien will aid in planning of the database structure and entry of marine geologic subsidence and uplift data from onshore and offshore basins. Oskin will devote one additional month to entry of onshore tectonic geomorphology and thermochronology uplift data.

Sorlien
University of Southern California
075639-U SCP04
Contributions to the SCEC Community Fault Model: Relating Onshore-offshore Stratigraphy and Fault-Fold Activity Beneath Santa Monica Bay
02/01/02-01/31/07
$20,000
This study proposes to utilize high resolution and industry seismic reflection data, well and seafloor geologic data, and swath bathymetric and backscatter data to investigate Quaternary deformation. We will correlate strata from ODP Site 1015 in Santa Monica bathymetric basin north to the Shelf Projection Anticline, and to sets of 800 X 2500 m grids of high-resolution reflection data that cross both the Dume segment of the Santa Monica fault and the San Pedro Basin fault and related folds. Ongoing NEHRP-supported structure-contour mapping of the top Miocene and top Repetto Formation horizons will be

extended to include one or more late Quaternary horizon as they are identified by correlation to onshore stratigraphy, and by biostratigraphic interpretation of a detailed list of benthic foraminifera for an offshore well. Several approaches will be used to correlate pre-latest Quaternary stratigraphy to the south of the Shelf Projection, possibly by regional correlations to wells offshore Redondo Beach, by correlation to our existing stratigraphic interpretations west and north of the Shelf Projection, or even correlating south of Palos Verdes (the Beta Field area). Activity on high-angle faults can be determined from vertical separation of a given horizon, and activity on folds can be determined by thinning and onlap of strata onto the fold. We will also incorporate submarine geomorphology using multibeam bathymetry and backscatter data, combined with high-resolution seismic reflection data. After the active faults and folds are identified and their kinematics interpreted, we can model the interactions between folding and blind thrusting, as well as strike-slip faulting. In this way the post-4 Ma average displacements can be related to modern deformation and seismicity.

Sorlien
University of Southern California
075639-K SCP03
Building the SCEC 3D Community Fault Model: Santa Barbara Channel and Santa Monica Bay
02/01/02-01/31/07
$30,000
We have produced digital structure-contour maps of deformed strata and of fault surfaces that cover a large area of Santa Monica Bay, Santa Barbara Channel, and offshore south-central California. SCEC funds are requested for extending and completion of existing digital maps and for construction of a web page for release of these maps. These maps and related information will be made available for use in the 3D Community Fault Model (CFM). This effort also includes improving the velocity model and depth conversion for certain maps, and improving the gridding from digitized contours for others. Mapped fault surfaces include the Red Mountain, North Channel, Pitas Point, and Dume (offshore Santa Monica). SCEC funding will allow us to construct digital surfaces on the offshore Oak Ridge fault and on the offshore Malibu Coast-Santa Cruz Island fault, and extend mapping on the offshore Red Mountain and other faults. We will have NEHRP funding during 2002 to complete mapping in northeast Santa Monica Bay, including the offshore Santa Monica-Dume fault, Palos Verdes fault (if present, *Fisher et al.*, 2001), and on strands of the broad San Pedro basin fault zone.

Sorlien
University of Southern California
075639AC SCP06
The faults responsible for the complete Palos Verde anticlinorium: Alternate representations for the Community Fault Model
02/01/02-01/31/07
$20,000
The Palos Verdes anticlinorium is the fold responsible for Palos Verdes Hills and the Shelf Projection (Fig. 1). The Compton blind thrust ramp was imaged and inferred to explain the southwest flank of Los Angeles basin (Shaw and Suppe, 1996). A SW-directed tectonic wedge continues southwest of the ramp on published cross sections (Davis et al., 1989; Shaw and Suppe, 1996). A SW-dipping backthrust that forms the roof of this wedge was called upon to explain uplift of the onshore Palos Verdes anticlinorium (Fig. 2). The magnitude of a multiple segment earthquake on just the ramp of the Compton thrust has been estimated at 7.0 (Shaw and Suppe, 1996). The ramp is beneath the southwest flank of the deep Plio-

Quaternary Los Angeles basin. Thus, although the Compton ramp may have a long recurrence interval, a multi-segment quake could be catastrophic. If the Compton blind thrust has a large-area offshore extension, then the hazard scenario would be different. Much of the Palos Verdes anticlinorium is offshore, and offshore stratigraphy and marine seismic data offer advantages to studying structure.

Our mapping shows that the anticlinorium continues beneath the offshore Shelf Projection for 30 km to the northwest, reaching beyond Santa Monica Canyon (Fig. 1). The Redondo Canyon fault has little effect on this continuity. Short-wavelength (1 to 2 km) folds, some with seafloor expression, are superimposed on the offshore anticlinorium. The crests of these short-wavelength folds were interpreted to be en-echelon with the onshore anticlinorium (Nardin and Henyey, 1978). Instead, the broad fold limbs of the anticlinorium, not the wrinkles, define the major structure. The southwest limb of the Palos Verdes anticlinorium is continuous and linear for 45 km, and is responsible for the 700 m-high offshore San Pedro escarpment. The anticlinorium is related to an additional 10 km of broad uplift of southern San Pedro Shelf, although it changes style and continuity there.

We interpret the SW-dipping fold limb to be a forelimb above NE-dipping blind thrust or oblique thrust faults (Sorlien et al., 2004; and 2004 SCEC annual report). Horizontal-axis rotation (progressive tilting) of an upward-widening zone absorbs thrust slip; slip on the blind faults gradually decreases updip as it is transformed into folding (Fig. 3). These offshore faults project in 3D into the SCEC Community Fault Model (CFM) representation of the Compton Thrust ramp, at least for the northwest 30 km of the structure (Fig. 4). Significant SW-dipping roof thrusts are not needed in this model. The NNE-dipping backlimb is also progressively tilting along at least 10 km of the northwest plunge of the anticlinorium (Fig. 5), suggesting a listric area on the underlying fault.

We call the NE-dipping blind faults the Shelf Projection blind fault and the San Pedro Escarpment fault, rather than the "upper Compton thrust". The existence of, and activity on, the Compton thrust remains controversial, and the faults that we mapped are inconsistent with the published tectonic wedge/roof-thrust model (Fig. 2). The upper tip of the Shelf Projection blind fault is quite deep beneath the base of the San Pedro escarpment. Individual seismic reflection profiles are not convincing to those who have not worked with the multiple data sets, and who do consider the folding in their fault interpretations. In fact, it was recently published that a SW-dipping normal fault is present along the base of the San Pedro Escarpment (Bohannon et al., 2004). This interpretation does not explain the anticlinorium.

The onshore Palos Verdes anticlinorium has been explained as due to right oblique-reverse slip on a restraining trend of the Palos Verdes fault (Nardin and Henyey, 1978; Ward and Valensise, 1994). However, it is difficult to explain how the offshore Palos Verdes fault could cause the offshore part of the anticlinorium. The SCEC CFM representation of the Palos Verdes fault beneath Santa Monica Bay shows a NNW-striking sub-vertical fault that strikes non-parallel to the WNW trend of the anticlinorium. The southwest limb of the anticline is broad and located up to 15 km southwest of the shallow Palos Verdes fault. The offshore anticlinorium cannot be explained by slip on a steep Palos Verdes fault. My mapping of seafloor splays of the Palos Verdes fault includes WNW-striking faults. However, these strands cannot explain the anticlinorium because one outcrops near the crest of the fold and another dips northeast away from the fold (Fig. 5). The restraining trend of the onshore Palos Verdes fault provides a component of contraction, but this contraction need not be taken up by oblique slip on the Palos Verdes fault; the contraction can instead partition onto the NE-dipping blind faults that we interpret. Oblique slip on the Palos Verdes fault no doubt modifies the shape of the onshore anticlinorium, but may have little affect on its offshore part.

I propose to provide to the CFM 3-D representations of the upper 2 km of several strands of the Palos Verdes fault in Santa Monica Bay. In addition, our representation a NE-dipping San Pedro Escarpment fault will be extended south at least 20 km (dashed part on Fig. 1). The northeast limb of the anticlinorium will be more completely defined using published cross sections and horizon structure-contour maps. The Palos Verdes fault was not interpreted by Fisher et al. (2003) in Santa Monica Bay because it was not clearly imaged on 1998 and 1999 USGS small airgun multichannel seismic reflection profiles. The preliminary map of the shallow Palos Verdes fault strands in Figure 1 was created using non-migrated deep-penetration industry data, a few migrated industry profiles, seafloor lineaments in the multibeam bathymetry, and suggestive features in my reprocessing of certain USGS profiles. I propose to include single-channel airgun or sparker USGS seismic profiles recorded in 1969, 1973 and 1981 to improve confidence in the shallow positions of Palos Verdes fault strands (Fig. 1B for 1973 and 1981 profile locations). High-resolution seismic was recorded coincidentally with the sparker or airgun data on many of the 1973, 1998 and 1999 USGS profiles. The third dimension will be represented using the industry data in my possession (e.g., Fig. 5), and any additional industry data that may become available during 2005. If necessary, I will offer to travel to Harvard to create a joint representation of the Palos Verdes fault with the Shaw and Plesch group. Once 3-D representations are complete on the Palos Verdes fault strands and San Pedro Escarpment fault, the fault attitudes will be modeled against a range of fault slip directions and magnitudes for structural relief, as we have done for the Santa Monica-Dume fault (see Sorlien et al. 2004 SCEC annual report). I will continue development of our model for broad fold forelimbs (Fig. 3).

Activity over the last 50 to 100 ka of the offshore Palos Verdes anticlinorium, the San Pedro Basin fault, the Palos Verdes fault, and the San Pedro Escarpment fault will be investigated. The top "Pico" is an unconformity 0 to 300 m below the seafloor of Santa Monica Bay (Fig. 6). USGS coring near LAX airport to ~250 m depth did not reach the last magnetic reversal at ~760 ka, and crossed an angular unconformity part way down (D. Ponti oral communications). My preliminary correlations identify routes where the post-50 ka strata drilled in ODP site can be correlated into Santa Monica Bay (Fig. 1 inset), and strata above this top Pico unconformity are younger than ~75 ka near the San Pedro Basin fault (see Normark et al., 2004). The youth of these strata may explain interpretations of inactivity on the northern Palos Verdes fault and the north limb of the offshore anticlinorium (e.g., Nardin and Henyey, 1978). Onshore-offshore seismic reflection profiles and cross sections are available near Venice/Playa del Rey (Davis and Namson, 2000), and I will investigate collaborations with USGS for onshore-offshore correlations of late Quaternary stratigraphy. Activity along the northwest offshore Palos Verdes anticlinorium is suggested by the following observations: (1) the floor of Santa Monica Canyon and early Holocene strata farther northwest are warped; (2) post-50 ka strata are deformed above the tips of the blind faults; (3) Palos Verdes Hills are uplifting; (4) the Shelf Projection has eroded, and the wave cut platform is shallower than low eustatic sea levels, suggesting rock uplift, above an inferred subsiding base level. Area balancing in cross-section yields up to 1.7 km of blind thrust slip beneath the Shelf Projection in the last ~2.5 M.Y., or more if sediment compaction and pressure solution are significant (Sorlien et al., 2004).

New funding will allow me to continue to provide SCEC fault and stratigraphic horizon representations, including for other areas. For example, I will provide a seafloor representation of the southern Hosgri fault and a 3D representation of the offshore western Santa Cruz Island fault. Funding will allow me to continue working with a graduate student, now working at Exxon-Mobil, to complete his thesis on the Palos Verdes anticlinorium and causative faults, and to modify the thesis for publication.

Sorlien
University of Southern California
075639Y SCP05
Alternate representation of the Channels Islands thrust for the Community Fault Model
02/01/02-01/31/07
$20,000
Ramp-flat kink models such as the fault bend fold and fault propagation fold models have been widely applied in southern California to infer fault geometry from deformation of shallow layers (Davis et al., 1989; Shaw and Suppe, 1994, 1996). A listric thrust model has been proposed to better explain structures characterized by progressively-tilting fold limbs (Seeber and Sorlien, 2000; see also Erslev, 1986 and Yamada and McClay, 2003). This debate is of more than just theoretical interest, as the fault-bend fold model predicts slip to be greater than or equal to backlimb width (Suppe, 1983), while slip above a listric thrust is related to both fold limb width and dip. The predictions for vertical motions are completely different between models, and vertical motion data can be used to produce a fault representation.

The SCEC Community Fault Model (CFM) includes the ramp-flat model for the Channel Islands thrust, and does not include a fault that can explain the active folding of Santa Rosa and San Miguel Islands (Fig. 1; Pinter et al., 2003). A major system of strike-slip faults, including the Santa Cruz Island fault, cuts the hanging-wall of the Channel Islands thrust (Fig. 1; e.g., Pinter and Sorlien, 1991). The intersection of Santa Cruz Island fault with the Channel Islands thrust (CIT) is at only 7.4 km (east) to 9.5 km (west) depth in the CFM representation (Plesch and Shaw, 2002). If the Santa Cruz Island fault is the product of slip partitioning on a deep oblique slip Channel Islands thrust, then it is not present in the footwall of the thrust. An ~8 km wide (downdip) fault is not a very large earthquake source. A listric Channel Islands thrust, starting with a moderate dip where imaged substantially south of the top of the Shaw and Suppe (1994) CIT ramp (Fig. 2), would likely intersect the Santa Cruz Island fault at much greater depth. The alternate listric thrust model is not included in the CFM because it has not been provided as a GOCAD surface; it has not been provided because the effort involved to do so is significant. This is not about proving one model or the other: it is about providing a representation of the published alternative model (Seeber and Sorlien, 2000).

Since the Channel Islands thrust immediately threatens a few dozen or hundred people, some feral pigs, a dozen or so buildings, and maybe a few black helicopters, why study it? Besides that it may root beneath the mainland, and may be linked to the Santa Monica Mountains thrust, the issues and techniques are similar for the study of blind faults responsible for uplift and folding of the Palos Verdes-Shelf Projection anticlinorium and others structures in and around Los Angeles basin (see Sorlien et al. Annual Report). The Channel Islands thrust will be studied first for the following reasons:

1: The representation of the Palos Verdes-Shelf Projection blind fault has just been provided and needs to be digested and published.

2: There is a much larger database of vertical motions across the Northern Channel Islands, including both uplift of the islands and subsidence around them (Fig. 3; Pinter et al., 2001, 2003).

3: The stratigraphy is better known and dated on the north limb of the Channel Island anticlinorium than on the north limb of the Shelf Projection (Fig. 3).

4: Industry seismic data show the geometry of the upper part of the Channel Islands thrust more clearly and to greater depth than does the data we used to map the Palos Verdes-Shelf Projection blind fault (Fig. 2; Fig. 5a in Seeber and Sorlien, 2000).

Sorlien
Burbank
University of Southern California
075639-A SCP01
SCEC2 Participation: The Volume of the Complete Palos Verde Anticlinorium: Stratigraphic Horizons for the Community Fault Model
02/01/02-01/31/07
$20,000
During 2005, we compiled published maps and our offshore mapping of onshore-offshore Palos Verdes anticlinorium. This mapping and compilation included fold axial traces and it produced a preliminary representation of the entire southwest limb of the anticlinorium. The upper few hundred meters of the San Pedro Escarpment fault was also mapped and then projected along it northeast dip to 3 km depth, and the digital representation provided to the Community Fault Model (Fig. 2). An anticlinorium is defined as “A composite anticlinal structure of regional extent composed of lesser folds.” (Bates and Jackson, 1984). The southwest limb of the Palos Verdes anticlinorium is continuous and linear for 50 km, and is responsible for the 700 m-high offshore San Pedro escarpment (Fig. 1). The anticlinorium is related to an additional 20 km of broad relative uplift of southern San Pedro Shelf and it southern slope. The topographic, bathymetric, and basement uplift is continuous for 70 km, forming a single anticlinorium, where 5 anticlinoria had been proposed by Nardin and Henyey (1978).

The Palos Verdes anticlinorium is the fold responsible for Palos Verdes Hills, the Shelf Projection, San Pedro Shelf, and San Pedro escarpment (Fig. 1). The uplift with respect to sea level (and a 0.9 km-deep datum) of Palos Verdes Hills was modeled as due to oblique slip on the onshore restraining double bend (“restraining trend”) of the right-lateral Palos Verdes fault (Ward and Valensise, 1994). This uplifting volume is two orders of magnitude less that the true volume of the anticlinorium (Fig. 1). The true volume incorporates structural relief, which is relative uplift above the subsiding Los Angeles, Santa Monica, and San Pedro basins. The onshore restraining trend of the Palos Verdes fault and the decrease of its right-lateral slip in Santa Monica Bay can only contribute a component of contraction and can only modify the shape of the fold. The anticlinorium must be folding above (a) low angle fault(s) comparable to it in extent.

The Torrance-Wilmington trend lies northeast of the Palos Verdes fault and is folding above the Compton ramp or a deeper equivalent (Shaw and Suppe, 1996; Davis et al., 1989). The Palos Verdes trend, including the Shelf Projection and part of southwest San Pedro Shelf, is southwest of the Palos Verdes fault and was interpreted to uplift above a SW-dipping roof thrust of a SW-directed tectonic wedge. If the Palos Verdes trend is viewed as a separate anticlinorium, its SW limb is much wider than is its NE limb, and the fold asymmetry suggests it is NE-verging. The interpretation that the southwest limb is a backlimb above a SW-dipping fault thus follows from the vergence (Davis et al., 1989, Shaw and Suppe, 1996). We view the structure as a single anticlinorium extending from below the 4 km-deep base Repetto contour in L.A. basin to beyond the base of San Pedro Escarpment (Fig. 1). This anticlinorium is offset by the right-lateral Palos Verdes fault, and the fold vergence is ambiguous.

The San Pedro Escarpment fault (SPEF) aligns in 3D with the Compton thrust ramp as represented in the SCEC Community Fault Model (CFM; Plesch, Shaw et al., 2002), and thus may be the same fault. The combined Compton-SPEF has twice the area of the Compton ramp alone. We interpret the SW-dipping limb of the Palos Verdes anticlinorium to be a forelimb above the NE-dipping SPEF. SW-dipping roof thrusts do not exist in our alternate representation.

Sorlien
University of Southern California
120044 SCP07
SCEC3 Participation: Modeling Blind Fault Slip from Quaternary Growth of Palos Verdes Anticlinorium, Off Shore Long Beach
02/01/07-01/31/09
$15,000

Late Miocene plate motion changes and formation of the Mojave restraining double bend in the San Andreas fault resulted in the widespread post-Miocene reactivation of pre-existing normal faults into thrust faults, and the inversion of basins into anticlinoria. One of these active fault fold structures, the Palos Verdes anticlinorium as we define it (PVA), is critical for earthquake hazard because of its location and size. The PVA is a regional NW-trending 70 km-long structure between the L.A. Basin and the Santa Monica-San Pedro Basins offshore and implies an active thrust-fault system of similar dimensions (Figs. 1, 2). The onshore restraining trend of the Palos Verdes fault contributes locally some contraction that may account for enhanced uplift of the Palos Verdes Hills (Ward and Valensise, 1994), but cannot account for the major part of the PVA. We have identified faults that may account for the PVA. The NE-dipping San Pedro Escarpment fault (SPEF) aligns in 3D with the Compton thrust ramp of Shaw and Suppe (1996) and may be the same fault (Figs 3, 4). The combined Compton-SPEF has twice the area of the Compton ramp alone, and could generate a M7.3 earthquake. The fault area and maximum magnitude are even larger if the Compton-SPEF is continuous down-dip with the lower Elysian Park fault (Fig. 4; Shaw et al., 2002). Santa Monica and Los Angeles Basins have subsided respectively 4 km and 5 km in the last 5 m.y., and this subsidence has probably continued through Quaternary time (Fig. 2; Wright, 1991; Sorlien et al., in press). Thrust faulting and folding are required in order to keep the Shelf Projection, Palos Verdes Hills, and San Pedro Shelf from sinking concurrently with the adjacent basins. In a simple fault-bend fold model that assumes similar long-term and Holocene subsidence rates, slip=0.8 mm/yr/sin(dip), or ~2 mm/yr for a Compton ramp dipping 22 degrees (Sorlien et al., 2006a). Strain is accumulating beneath and north of downtown Los Angeles (Argus et al., 2005), which may stem from creep on the downdip part of the fault system. Despite different names for its different parts, a single major thrust fault may account for the west flank of the LA Basin and be a potential source of rare but catastrophic ruptures.

The introductory text is a hypothesis for activity on a major fault system beneath Los Angeles metropolitan region. Current seismic hazard models do not include this thrust system because borings and a trench did not find kinking of 15-20 ka strata at the base of the NE-dipping fold limb, where expected by a particular structural model (Mueller, 1997; **www.consrv.ca.gov/cgs/rghm/**psha/**fault_parameters**/pdf/B_flt.pdf). However, large anticlinoria can form above active thrust faults without a requirement for such kinking (e.g., Seeber and Sorlien, 2000). High-resolution seismic reflection data and core holes recently showed folding of inferred Holocene strata at the base of the Compton backlimb in south-central Los Angeles (Leon et al., 2006). Figure 4 shows a cross section across Palos Verdes anticlinorium and downtown Los Angeles that shows both Compton ramp and Puente Hills thrust. The potentially catastrophic effects of a Puente Hills earthquake are now well-known in the SCEC community (Field et al., 2005, Olsen and Heaton, 2006). In contrast, there is no agreement on the existence of, geometry of, or activity on the San Pedro Escarpment-Compton-Lower Elysian Park thrust.

Proposed Work

I have already provided a 3D representation to the SCEC CFM of the shallow part of two NEdipping faults beneath San Pedro Escarpment and it southern continuation across a right step (Figs. 2, 3, 4, 5), although they are not yet part of CFM3.0. I recently started a Kingdom Suite (3D industry interpretation and imaging system) project that includes the Western Geophysical WC80 migrated seismic reflection data across San Pedro Shelf and the adjoining escarpment. These and other data are available in digital form at a USGS web site (**http://walrus.wr.usgs.gov/NAMSS/index.html**). USGS high-resolution multichannel seismic reflection data will be added to this project (Sliter et al., 2005). The faults beneath the escarpment are not imaged below the water bottom multiple (~1 km) on either data set. In contrast, the Palos Verdes and Cabrillo faults are well-imaged to Catalina schist basement on the industry data.

At least two types of modeling will be done in order to infer fault dip below where imaged. The first involves interpreting structural relief from stratigraphic horizon mapping, and modeling slip direction and amount from know fault attitude, or modeling faults attitude for a known slip direction and range of slip magnitudes. Structural relief (SR) at any point along the fault can be computed from the geometry of the fault over the slip, assigned to be in the x-direction (Sorlien et al., in press).

(1)$SR=\Sigma i 1km*\sin(\alpha i)*\tan(\delta i)$

Where α is the angle between the local slip vector and local fault strike, and δ is fault dip. The dip and strike of the fault and the structural relief of the ~4 Ma horizon was measured at each of 36 cross sections spaced at 1 km across the Santa Monica-Dume fault. The summation is carried out over the cumulative slip (Fig. 6). For the Palos Verdes fault, pure right-lateral slip can be inferred at the point where the fault transitions from transpression to trantension. A range of fault dips below top basement and a range of slip magnitudes can be modeled to match structural relief through offshore bends of the Palos Verdes fault. Preliminary mapping shows map-view bends in the San Pedro Escarpment fault system (Fig. 2). The imaged shallow fault attitude can be used to model slip direction and amount vs. structural relief. The deeper dip of the faults will be explored using Trishear (fault-fold) modeling.

Steidl
University of Southern California
075639-L SJP06
SCEC3 Participation: SCEC Borehole Instrumentation Program
02/01/02-01/31/07
$30,000

One of the major goals of the Center is to compute theoretical seismograms for scenario earthquakes in the Los Angeles and Southern California region. Existing strong-motion data are used to calibrate and improve our computational techniques. Ground motions recorded at strong motion stations throughout Southern California are a combination of the complex earthquake source process, the propagation path from the source zone to the station, and the local near-surface site conditions at the station. Separation of source, path, and site effects is limited by the current availability of data, the lack of detail in our knowledge of the crustal structure, and our understanding of the earthquake source process. Widespread and varied ground motions and damage patterns over short distances produce a large degree of uncertainty in our ability to predict ground motion from future earthquakes. In order to reduce the uncertainty in our theoretical seismograms of possible scenario earthquakes, we will observe and remove the near-surface site effect at a few select stations having "typical" southern California soil profiles by using borehole instrumentation. Observations from the SCEC borehole project allow for direct estimation of site effects, provide a test for the calibration and improvement of physical models of soil response, and give us a clearer picture of the incident ground motion that can then be used to study in more detail the earthquake source process and the regional crustal structure.

Much of the variability mentioned above is caused by the local near-surface site conditions and shallow crustal structure. The upper several meters to several tens of meters in the geologic section have major influence on amplification or deamplification of seismically generated ground motions and the initiation of ground deformation or ground failure. Evaluation of ground response and ground deformation in these upper layers, and the interaction with foundations and structures, is a critically important aspect of safe and economical engineering design. One of the primary goals of SCEC is to generate analytical and empirical models for accurate prediction of ground response and ground deformation due to earthquakes. A required element for the development of these models is well-instrumented field sites where actual ground response and deformation can be monitored during earthquake shaking to provide benchmark case histories for model development and verification. Records from a number of sites with a variety of soil types and geometric configurations are needed to provide a range of site conditions commensurate with those commonly encountered in engineering design.

Under this proposal, the SCEC borehole instrumentation program will continue ongoing efforts to increase the number of these benchmark sites in the Southern California region (currently nine) and to make the data available in real-time through the SCEC data center. We will continue to use the data to develop the numerical techniques for linear and nonlinear site response analysis, dynamic modeling of soil behavior at large strain, and analysis of source and path properties. We will seek out new targets of opportunity to provide observations from deep rock sites in close proximity to active faults. Collaborations with other agencies will continue to allow us to stretch the SCEC dollar and provide significant value for the cost. We will also contribute to the short-term goals of the implementation interface group through a newly formed collaboration with our engineering colleagues and the NSF engineering funded George E. Brown Jr. NEES program.

Steidl
University of Southern California
075639-V SJP09
Attenuation Analysis of Borehole Data for CVM
02/01/02-01/31/07
$50,000
The method used in this project will be nonlinear waveform inversion. The model parameters to be determined in the global inversion method developed by *Liu et al.* (1995a, b) are Q_o and *P*, where the attenuation is defined as $Q(f) = Q_0 f^P$. We assume this standard functional form for the frequency dependence of Q and use the global inversion to determine the dependence on a site-by-site basis. The exponent *P* is bounded by the two end member cases where *P* = -0.5 and *P* = 0.5. It is possible to invert for other material properties using this global inversion scheme; however, we will fix the other material properties using the independent site characterization data at these sites and focus solely on attenuation.

The forward model will be calculated using a modified 1D Haskell transfer matrix that incorporates the ability to accurately include frequency dependence of attenuation. The synthetics will be generated using the borehole data as the input. Surface observations and synthetics will then be transformed into the wavelet domain for the global inversion. We have had success in the past in modeling waveform data from borehole arrays to frequencies of up the 10 Hz (*Steidl et al*., 1998). Initial inversions will span the frequency range of 0.1 to 10 Hz, and depending on the results, we may attempt to push the upper frequency limit higher, or alternatively, compute a high frequency inversion in the frequency domain, matching spectra instead of waveforms.

Steidl
University of Southern California
075639-M SJP07
SCEC3 Participation: SCEC Portable Broadband Instrument Center
02/01/02-01/31/07
$160,000
The Portable Broadband Instrument Center's (PBIC) ability to respond rapidly to a major Southern California earthquake with the deployment of seismographs in the near-source region is a critical asset of SCEC. This has been highlighted by the success of the PBIC deployments from four major earthquake sequences in the past decade. The ability to conduct innovative experiments using PBIC equipment in between earthquake sequences is another important asset of SCEC. The list of PBIC publications is a testament to the importance and success of the SCEC PBIC program and how it has facilitated research over the years. This proposal is to continue support of the operations and maintenance of the existing PBIC equipment, to continue the software and web development, and to serve as seed funding for a new state-of-the-art PBIC proposal that will be submitted to the NSF Major Research Instrumentation (MRI) program in January, 2003. This new PBIC would include wireless communication technology and next generation network dataloggers for seamless integration of data into the Southern California TriNet regional network, or any other regional network that supports real-time telemetry of data.

Tanimoto
University of Southern California
075639-W TTP06
Testing and Improving the SCEC Community Velocity Model 3.0 with TriNet Broadband Data
02/01/02-01/31/07
$25,000
Broadband seismic data from TriNet provides an excellent opportunity to test the SCEC Community Velocity Model 3.0 (*SCEC CVM 3.0; Kohler et al.*, 2002). Our preliminary analysis in the first year indicated that surface waves for frequencies about 20-50 mHz are not fit by the CVM 3.0. We propose to analyze teleseismic surface waves and body waves recorded by TriNet and to construct an improved model. The ultimate purpose is to construct a model of large-scale 3D structure in Southern California which will serve as a good reference model. The resulting model will enhance the CVM 3.0 in many ways. For example, S-wave velocity structure in the crust and mantle will be better constrained because of the addition of surface wave data to the body wave data. The model will provide an extension into the oceanic region because of new TriNet stations and the accumulation of island station data. The model will also expand the mantle region covered by the CVM 3.0. The mantle in the CVM 3.0 spans a region smaller than the crustal region. The model will provide a well-constrained overview of long-wavelength features in the entire Southern California region and thus will help us understand the overall tectonic features. Our preliminary maps contain some surprising features that will potentially lead to a new understanding of large-scale tectonics in this region.

Tanimoto
University of Southern California
075639-AB TTP07

Improving S-wave Velocity in the SCEC Community Velocity Model through Teleseismic Broadband Data
02/01/02-1/31/07
$25,000
Our target for 2005 is to perform the following items related to the retrieval of S-wave velocity structure from CISN data. The order is given in terms of priority.

Azimuthal anisotropy: finalize our estimates for surface wave azimuthal anisotropy. Patterns of azimuthal anisotropy will be clarified and 3D phase velocity maps will be estimated jointly with azimuthal anisotropic terms. Particle motion: Surface wave particle motion for periods below about 30 seconds seem to deviate from the great circle paths. We can now determine the directions at each station and incorporate them for structure retrieval. We will finish the particle motion analysis of surface waves for the events we have in hand. Joint inversion: We will attempt a joint inversion of surface waves and body waves, starting from the SCEC CVM 3.0 (Kohler et al., 2002; Magistrale et al., 2000; Hauksson, 2000). Through this process, we will clarify which aspects of the crust and mantle structure need to be modified in CVM 3.0.

CFM as a starting model: For smaller wavelength scale (in Los Angeles basin in particular), the Community Fault Model is perhaps a better model for the crust. We will attempt an inversion using CFM in the Los Angeles region and examine how it will improve the fit to our data set.

S-wave splitting data: While this project mainly seeks to improve S-wave velocity structure in CVM/CFM, we will try to understand the implications of having two separate data sets on anisotropy: surface wave azimuthal anisotropy and S-wave splitting data. Splitting measurements by Polet and Kanamori (2002) and our azimuthal anisotropy data will be examined in detail.

Tanimoto
University of Southern California
120044 TTP09
SCEC3 Participation: Using Seismic noise for the purpose of improving shallow S-wave velocity models
02/01/07-01/31/09
$20,000
In order to find an anisotropic model that explains body-wave splitting data and surface wave data, we will perform the following analysis:

- **Re-examination of data:** We will examine and augment S, and SKS splitting data and Rayleigh wave data thoroughly to make sure that they are well constrained and resolved. Possible pitfalls in measurements such as noise effects from microseisms on SKS measurements and complex propagations for Rayleigh wave propagation will be analyzed in detail.
- **Examine theory for surface waves and body waves:** Effect of anisotropy on surface waves has been solved about 20 years ago including spherical effects but their practical implementation remained to be very primitive such as those discussed in Montagner and Nataf (1986). There are some parameter space, or the degrees of freedom, that may be left in order to make surface wave and body wave compatible.
- **Multi-layer modeling:** intuitively, our data seem to suggest that a three-layer model is at least required to explain both types of data. We will examine how many layers we will need and what type of anisotropy is required in each layer.

Anisotropy and S velocities in the SCEC_CLM: Our data on S velocities and anisotropy will be input to the California Lithosphere model. In addition we will include data from the Sierra Nevada Earthscope Project (SNEP), which is adding significantly to the SKS determinations

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Tanimoto
University of Southern California
120044 TTP10
SCEC3 Participation: Constraining the Evolving Architecture of the Plate Boundary Zone Through 3D Seismic Velocity and Anisotropy Mapping
02/01/07-01/31/09
$15,000
We will analyze seismic noise recorded by California Integrated Seismic Network and work toward the following three milestones of the project:

1. Derive of shallow S-wave velocity results (depth 0-10 km) by the ZH ratio method.
2. Derive crustal S-wave structure from the noise cross-correlation approach.
3. We will then communicate the results to the Harvard group for updating CVM 5.2.
