Awards Administered 2005-2006

Archuleta
University of Southern California
069203
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
National Science Foundation
CMS-0201264
COSMOS Virtual Data Center
09/01/02-08/31/07
<u>$397,395</u>
Agency: COSMOS
2003-02
COSMOS Virtual Data Center
09/01//02-08/31/07
<u>$155,000</u>
California Dept. of Conservation-California Geological Survey
1005-807, 1005-822
07/01/05-08/31/06
<u>$109,500</u>

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
National Science Foundation
EAR-0512000
Resolution, Robustness and Dynamics Based on Inversions of Seismic and Geodetic Data of the 2004 Parkfield Earthquake
07/01/05-06/30/07
$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 M_W 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.

Inverting all of the data to find a "best" model of the faulting process will be done, but this data set provides a much greater opportunity. With the abundance of data one can investigate the inversion process itself and determine which of the kinematic parameters are well resolved by the data; which data control kinematic features that are robust among different data sets; what are the tradeoffs between different velocity models and the choice of data. These issues are almost never addressed because most inversions must use all of the available data to constrain the numerous free parameters of the inversions. By carefully analyzing the subsets of the data, all of the data and different data types, the resolution of the kinematic parameters can be quantified. The kinematic features that are robust will define the earthquake. Features that are robust and well resolved are critical for deriving stress changes on the fault that are the initial conditions for dynamic models.

The physics of an earthquake must be inferred from observations. The Parkfield data, quantity and quality, provide a rare opportunity to deduce initial stress conditions from robust, well-resolved kinematic models. Dynamic models may provide answers to why the 2004 earthquake is so different from those in 1966 and 1934 and if seismicity is correlated with the stress that drives the mainshock. Careful analysis of the uncertainties in inversions will lay the foundation for future inversion studies when the data are not so plentiful.

There were no obvious precursors to the 2004 Parkfield earthquake. By knowing the spatial distribution of the initial stress that is consistent with the dynamics one can correlate prior seismicity patterns as well as inferring the magnitude of strain changes that might be expected prior to the mainshock. A key finding will be how sensitive are the kinematic parameters to the choice of data, both in type and in the location of the sensors. This will aid in the design of future sensor deployments to maximize our inversion results from other events. The proposal supports one female graduate student and one soft-money research scientist (half-time).

Archuleta
University of California –UC IGPP
04-08-16L-1532
Heterogeneity of Stress in the Crust and Its Effect on Earthquake Rapture
10/01/04-09/30/06
$65,800
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
Carlson
Department of Interior
06HQGR0046
Model Uncertainty in Earthquake Hazard Analysis
01/01/06-12/31/06
$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
Department of Interior
05HQGR0059
Predicting the Spatial Variability of Site Response
01/01/05-6/30/06
$52,013

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 liquifaction, 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 cna 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 variability that site response has on predicted ground motion.

Atwater
National Science Foundation
DUE-0205928
NSF Director's Awards for Distinguished Teaching Scholars
Animation for Visualization of Earth Processes and History
07/01/02-06/30/07
$305,000

My works on the plate tectonic evolution of western North America are especially highly cited, used, and respected. They earned me election into the National Academy of Sciences in 1997. I continue to do research on many aspects of this subject. My teaching goals are always two-fold, both to instill as much understanding as possible of the way the earth works, and also to convey my own love of the beauty, excitement and rigor of the scientific endeavor.

In recent years I have experimented with the creation of multi-media visualization products for the understanding and teaching of earth subjects. My initial animations and movies have met with great response, and are used in numerous classrooms at U. C. S. B., across the nation and around the world. I believe a major portion of the human population learns best from imagery, especially moving images, and I am very excited about the new multi-media tools that make this form of communication so much more possible. Moving imagery is especially useful and helpful for the teaching of geology, since the subject is so visual and is often far outside ordinary human scales of time and space.

I am presently refining regional geological animations and materials for southern California. If this award is granted, I plan to expand the geographic reach of this work by creating an Educational Multimedia Visualization Center for visiting teacher-scholars. Many colleagues who have seen my animations at meetings and lectures have immediately asked how to create their own. The center will allow experts in the geology of their own regions/disciplines to bring their traditional images and knowledge and to transform them into animations and presentation packages. They will return home with these products and also with a new array of skills to share around their own institutions. Their imagery products will join my works that are already out in film, videotape, as freeware on the web and as materials in the NSF-funded digital libraries of ADEPT and DLESE. Indeed, the ADEPT group is based at U.C.S.B. and is interested in developing a streamlined process for transferring content generated at the Educational Multimedia Visualization Center into their online holdings.

The award will honor and facilitate my efforts and those of many visiting colleagues. Equally important, it will recognize and honor the exceptional support this campus gives to undergraduate teaching through the U.C.S.B. Instructional Development Office. This world-class group supplies consultation and support for all aspects of teaching. The proposed Multimedia Visualization Center will build upon the long experience and excellent infra-structure of this organization, extending its services to off-campus visitors. Thus, visitors will return home with their own projects and also with new ideas about instructional support possibilities. Likewise they will share with us the innovations of their home institutions that we may learn from them and pass them along.

Becker
National Aeronautics & Space Administration
NAG5-13413
A Re-Examination of Nitrogen Heterocyclic Compounds in Extraterrestrial Samples
09/15/03-09/14/05
$80,000

The biological role of purines and pyrimidines as coding elements of ribonucleic acids (RNA) and deoxyribonucleic acids (DNA) have led to broad interest in the isolation, characterization and formation of these compounds and their related derivatives in meteorites (*Folsome et al*., 1971, 1973; *Hayatsu* (1964), *Hayatsu et al*., 1975; *Van der Velden and Schwartz*, 1977; *Stoks and Schwartz*, 1981 a,b, 1982; *Pizzarello et al*. 2001). Geochemical studies of meteorites, especially Murchison, have provided some valuable clues about the mechanism of formation of other important organic compounds such as amino acids, via the Strecker-synthesis (*Peltzer and Bada*, 1978); however, attempts to establish a mechanism of formation for N-heterocycles remains problematic.

The problems encountered in some of the earlier work are, in part, due to very different approaches in isolating and analyzing these N-heterocycles in carbonaceous chondrites. For example, *Folsome* (1971, 1973) examined charcoal absorbates of hot-water and hot formic acid extracts using GCMS and found mainly 4-hydroxypyrimidine, two isomeric methyl-4-hydroxypyrimidines and some non-biological compounds (e.g. pyrimidines, quinolizine). Curiously, none of the biologically occurring purines or pyrimidines was detected. This was followed up by *Hayatsu et al.* (1975) using both the *Folsome et al*. extraction method (1971, 1973) and much harsher extraction procedures (acid hydrolysis using 3-6 M HCL or trifluoroacetic acid) coupled to detection by direct probe MS without any further derivatization. They detected aliphatic amines and C_2-C_6 alkyl pyridines but no 4-hydroxypyrimidines via the *Folsome et al.* (1973) method. Using the stronger acids, two of the biological purines adenine and guanine were detected as well as the triazines melamine, cyanuric acid, urea and guanylurea, which have no known biological function.

Becker
Johns Hopkins University
862462
Organic Synthesis in Hypervelocity Impacts
11/15/02-06/30/06
$36,000

We propose to undertake a new study of the possible synthesis of pre-biotically relevant organic compounds in hypervelocity impacts. The organic matter on planetary bodies originally derived from a combination of endogenous and exogenous processes, with impact shock and post-impact recombination playing a potentially significant role (e.g., Chyba and Sagan 1992, Nature 355, 125). The inventory of organic species that may have resulted from recombining hypervelocity impact plasma remains somewhat speculative, especially for impacts above 20 km s-1 where current gun experiments cannot reach. For airless small bodies and moons, such studies are important for comparison to, and in conjunction with, the important chemical processing of ices by UV radiation. For planets with atmospheres, particularly Earth, such knowledge is needed to compare with the potentially complementary set of species synthesized in impact shock. Pulsed laser ablation (LA) is a highly-promising experimental probe of this high velocity regime (e.g., Pirri 1977, Phys. Fluids 20, 221; Mukhin et al. 1989, Nature 340, 46). A unique experimental design permits the study of LA products with both post-analysis of deposited films and high-sensitivity in situ time-of-flight mass spectrometry. Initial results have shown that exobiologically-pertinent hydrocarbon oligomers with a wide range of energies and ionization states are produced even from a completely atomized plasma. With this setup, and with an enhanced derivative design with improved control of laser coupling, energy, and spot-size, we will obtain a comprehensive analysis of the plasma recombination problem with standard carbon-matrix, meteorite, and carefully tailored ice analog materials. Dr Becker will evaluate samples in her laboratory using LDMS and high performance liquid chormatography could to a photo-diode array detector to further evaluate the organ compounds formed in the hypervelocity impact experiments.

Becker
National Aeronautics & Space Administration
NAG5-11560
Interstellar Organic Molecules and the Origin of Life: The Role of Exogenous
12/01/01-11/30/05
$180,249

Extraterrestrial bodies such as asteroids, comets and their associated dust, played a significant role in the early history of life on Earth and perhaps other planets. The study of life under such extreme conditions requires knowledge of such fundamental issues as the nature of the organic material and the chemical processes that led to their formation in space, the chemistry of asteroids and comets, and the preservation of organics in the early terrestrial environment. In this proposal we outline a program to examine the role of exogenous delivery of organic compounds to the early Earth by studying organic-rich meteorites (e.g. Muchison meteorite), sediments associated with giant impact events (Cretaceous/Tertiary 'K/T' boundary) and the inter-planetary dust (IDPs) found in deep-sea sediments (DSDP drilling cores). We have developed several new techniques to search for specific organic tracers that will allow us to examine the contributions of exogenous delivery in providing complex organic compounds to the early Earth and to investigate the effects of such events on the biostratigraphic record over the past several million years. Specifically, we will isolate fullerenes with trapped noble gases (*Becker et al*., 1996) and abiotic amino acids (a-AIB and isovaline; *Zhao and Bada,* 1989) in our samples and will compare the relative concentrations of these compounds to evaluate the preservation and accumulation of organics being delivered to the Earth. In addition, we will carryout laboratory experiments to probe the level of chemical complexity that can be reached as a result of exogenous delivery and will examine the complexation of organic compounds to specific mineral phases. Confirmation of the flux of extraterrestrial material in sediments throughout geologic time and its association with changes in the biostratigraphic record could have broad implications for the origin and evolution of life on the early Earth and perhaps other planets.

Becker
National Science Foundation
OPP-0229917
Collaborative Research: Permian-Triassic Mass Extinction in Antarctica
06/01/03-05/31/06
$148,985

This proposal is to continue multidisciplinary studies of the fluvial sediments in Antarctica for evidence of what caused the greatest of all mass extinctions in the history of life at the Permian-Triassic boundary. This boundary was until recently difficult to locate and thought to be disconformable in Antarctica. New studies, particularly of carbon isotopic chemostratigraphy and of paleosols and root traces as paleoecosystem indicators, together with improved fossil plant, reptile and pollen biostratigraphy, now indicate the precise location of the boundary and have led to local discovery of iridium anomalies, shocked quartz, and fullerenes with extraterrestrial noble gases. These anomalies are associated with a distinctive claystone breccia bed, also known in South Africa and Australia, and taken as evidence of deforestation. There is already much evidence from Antarctica and elsewhere that the mass extinction on land was abrupt and synchronous with extinction in the ocean.

The problem now is what led to such death and destruction. Carbon isotopic values are so low in these and other Permian-Triassic boundary sections that there was likely to have been some role for catastrophic destabilization of methane clathrates. Getting the modeled amount of methane out of likely reservoirs would require such catastrophic events as bolide impact, flood-basalt eruption or continental-shelf collapse, which have all independently been implicated in the mass extinction and for which there is independent evidence. Teasing apart these various hypotheses will require careful re-examination of previously discovered boundary beds, and search for more informative sequences, as was the case for the Cretaceous-Tertiary boundary.

This is collaborative research on geochemistry and petrography of boundary beds and paleosols (by Retallack), on carbon isotopic variation through the boundary interval (by Jahren) and on fullerenes, iridium and helium (by Becker). Our primary field site for the first season is likely to be Coalsack Bluff in the central Transantarctic Mountains, with short visits also to Graphite Peak, Mt. Wild, Fremouw Peak and Mt. Boyd. For the second season we plan to focus on Portal Mountain in southern Victoria Land, with short visits also to Mt. Crean, Mt. Fleming and Shapeless Mountain.

Becker
National Science Foundation
EAR-0341972
Bedout: An End-Permian Impact Site Off-Shore Northwestern Australia
08/15/03-10/31/05
$30,000

Becker
National Aeronautics and Space Administration
NNG04GJ36G
Traces of Catastrophe at the End Permian
05/01/04-04/30/07
$312,307

Becker
National Aeronautics and Space Administration
NNG04GC17G
Atmospheric Pressure Matrix Assisted Laser Desorption/Ionization Ion Trap Mass Spectrometry (AP-MALDI-ITMS): A Novel Approach to the Characterization of Organics in Rocks and Ices on Mars
01/15/04-01/14/07
$323,873

Becker
National Aeronautics and Space Administration
NNG06GG87G
Atmospheric Pressure Matrix Assisted Laser Desorption/Ionization Ion Trap Mass Spectrometry (AP-MALDI-ITMS): A Novel Approach to the Characterization of Organics in Rocks and Ices on Mars
4/15/06-4/14/07
$631,674

Boles
Department of Energy
DE-FG02-96ER14620
Fluid Flow in Faults: Process and Effects from Modern and Paleo Systems in a Transpressional Tectonic Setting, Southern California
12/01/01-1/31/07
$637,467

We propose to expand our study of heat and mass transfer related to faulting. Future studies will include estimating spatial distribution of fault permeability as indicated by diagenetic effects and determining mechanisms and evolution of fluid movement. Our work will continue to focus on transpressional sedimentary basins of southern California, which have been actively deforming since Miocene time

Specific questions to be addressed include:

- How does permeability of the fault system and associated fluid movement evolve over time?

- What techniques are most effective at detecting thermal pulses in the fault environment?

- What diagenetic evidence is there to support the hypothesis that fluid movement is episodic and rapid?

- What are the geochemical and thermal implications of episodic fluid flow?

- What evidence is there that solid earth tides affect fluid (gas) movement in fault systems and submarine seepage at continental margins?

The study of natural seepage along continental margins has become a frontier area for geofluids research (Parnell, 2002), yet we know of few groups like ours linking methods from hydrogeologic modeling and geochemistry/sedimentary petrology to problems of flow in faulted systems. This is a true collaborative study combining field and analytical observations and data generated by the UC Santa Barbara team under the direction of James Boles with hydrogeologic and poroelasticity modeling generated by the Johns Hopkins University team under the direction of Grant Garven.

Boles
American Chemical Society - PRF
PRF# 39823-AC2
Dissimilar Mineral Interfaces: Understanding Mica/Quartez Surface Interactions
07/01/2003-08/31/2006
$79,495

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
Understanding the Role of Clay Mineral Surface Interactions in Pressure Solution
07/01/04-06/30/07
$384,978

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 liquifaction, 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 cna 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 variabily that site response has on predicted ground motion.

Burbank
National Science Foundation
EAR-0196414
Collaborative Research: Geomorphic-Geodynamic Coupling at the Orogen Scale: Himilayan Transec in Central Nepal
03/15/01-12/30/06
$1,381,008 and REU supplement $14,194

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 Science Foundation
EAR-0117242
Collaborative Proposal: Scaling and Displacement Relationships for Thrust Faults
04/01/2001-12/31/2006
$214,464 and $13,482 REU supplement

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 field work is focused on the Ostler Fault system in the South Island of New Zealand and was begun in mid-January, 2002. The initial field work 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 backlimbs 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-0229911
Collaborative Research: Extrusion and Rotation During Intracontinental
02/15/03-01/31/07
$52,985

Despite recent advances in our understanding of the mechanical and thermal response of continental lithosphere to collisional orogenesis, important controversies remain. One of these centers on the role of large strike-slip faults during intracontinental deformation, and whether these structures 1) control the lateral 'escape' of quasi-rigid blocks in response to continental convergence (e.g., *Tapponnier et al*., 1982), or 2) reflect the passive localization of strain in a pervasively deforming and shearing crust (e.g., *England and Molnar,* 1990). The models make very different predictions regarding the variation of displacement along strike-slip faults, the relationship of fault displacement to deformation of the surrounding crustal blocks, and the nature of accommodation of slip at the terminations of the faults. In eastern Tibet, continuing debate over the nature of active deformation reflects, to a large degree, the limited number of rigorous geologic tests of these predictions.

The Kunlun fault is a first-order structural feature in the central and eastern Tibetan Plateau, where it presents a key opportunity to test among competing hypotheses for the role of strike-slip faults in the active deformation of eastern Tibet. Although Holocene slip rates appear to be uniform at ~11mm/yr along the central portion of the fault (*Van der Woerd et al.*, 2000), several observations suggest that significant left-lateral shear along the eastern Kunlun fault does not reach the margin of the Tibetan Plateau: 1) the active trace of the fault on remote sensing (e.g., *Tapponnier and Molnar*, 1977) cannot be distinguished east of ~102°E; 2) field observations (Kirby) confirm that scarps associated with the Kunlun fault are not present east of this region; and 3) geodetic surveys indicate that, at present, little resolvable left-lateral shear passes through the eastern margin of the plateau (*Chen et al*., 2000). Determining what happens to left-lateral shear along the easternmost portion of the Kunlun fault is critical if we are to understand its kinematic and dynamic role in deformation of eastern Tibet and more generally the role of strike-slip faults during intracontinental deformation.

We propose to test several hypotheses regarding the mechanisms of transfer and/or accommodation of displacement at the apparent termination of an intracontinental strike-slip fault:

- *Hypothesis 1:* Displacement is transferred to kinematically linked, strike-slip faults that:
    a. transmit displacement across and beyond the plateau margin, or
    b. transmit displacement to shortening structures at the plateau margin.
- *Hypothesis 2:* Displacement is absorbed by distributed shortening within the plateau resulting in crustal thickening.
- *Hypothesis 3:* Displacement represents passive rotation of faults in response to a diffuse, clockwise regional shear.

Testing these hypotheses will focus on the following tasks:

- Determining Late Pleistocene-Holocene slip rates along the easternmost segment of the Kunlun fault, with special attention to potential variations along strike.
- Establishing the geometry, kinematics, and rates of displacement on candidate accommodation structures (both within the plateau and at its margin).
- Assessing the magnitude and distribution of differential rock uplift and river incision in the Anyemaqen Shan (the prime candidate for shortening within the plateau) This study promises to bring a detailed chronologic perspective to bear on the nature of accommodation of strain at the terminations of large, intracontinental strike-slip faults.

We will document the presence or absence of displacement gradients present near the ends of such structures. The study will define the relationship of fault displacement to regional deformation patterns and will determine some of the mechanisms by which displacement is transferred to other structures. Finally, it will determine to what degree fault displacements are linked to deformation of the bounding blocks. The combined results will yield critical new insights into the problem of extrusion versus rotation during continental deformation.

Burbank
National Science Foundation
EAR-0230403
Geologic Versus Geodetic Rates of Convergence in the Southeastern Tien Shan, China
03/01/03-02/28/07
$272,212

As geodetic studies yield increasingly precise representations of decadal patterns of crustal deformation, they pose intriguing problems that, in most sites, are unresolved at present. Geodetically defined strain demands explanation: Given a regional strain gradient, how is strain partitioned across the intervening terrain? Do multiple structures accommodate the deformation, and, if so, how do they interact to produce the regional stain pattern? Do geodetic strain rates at decadal scales provide a good representation of long-term strain rates, and, if so, at what spatial scales? How far back in time can geodetic strain rates be extrapolated, and are they consistent with geologic data on the age of initial deformation and geologic deformation rates through time? Are regional rotational gradients defined by geodetic data consistent with rotations recorded by syntectonic strata?"

Several geodetic and geologic studies along strike-slip fault zones, such as the San Andreas, suggest that a reasonable match commonly exists between the geologic and geodetic data, such that the geodetic strain rates (*Wdowinski et al*, 2001; *Hudnut et al*, 2002) match the sum of documented geologic slip rates on known faults (*Sieh and Williams*, 1990; Weldon, 1996; *Reheis and Dixon*, 1996). In contractional mountain belts, however, the correlations of short- and long-term strain rates (geodetic versus geologic) are more ambiguous. Similar geodetic strain gradients can be accommodated by very different structural patterns. For example, across both the Kyrgyz Tien Shan (*Abdrakhmatov et al*, 1995; *Reigber et al*., 2001) and the Nepalese Himalaya (*Larson et al*, 1999; *Wang et al*, 2001), geodetic data define regional strain gradients of ~20 mm/yr of shortening. Despite similarities in overall geodetic rates, the geologic data define striking contrasts in how this strain is accommodated.

Burbank
National Science Foundation
EAR-0408675
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 suggests 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
Collaborative Research: Upward and Outward: Tibetan Plateau Growth and Climatic Consequences
09/01/05-08/31/06
$408,674

The Tibetan Plateau not only serves as the worldís best laboratory for studying intracontinental deformation, but also acts as the continentsí 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, Tibetís 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.

The interaction between tectonics (large-scale deformation of Earthís crust and upper mantle) and environmental change (especially climate) is emerging at the forefront of the earth sciences. Because of Tibetís 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
National Aeronautics and Space Administration
NAG5-13758
Tectonic-Climate Interactions in Active Orogenic Belts: Quantification of the approach to steady-statetopography with SRTM data
10/01/2003-09/30/2007
$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 landsliding.
• 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 field work 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
Illuminating the evolution of thrust-fault systems using deformed geomorphic markers
01/01/05-08/31/07
$79,600

The growth and development of thrust faults and associated folds in compressional tectonic regimes both generate and destroy structural petroleum traps. Detailed observations of active thrust systems can provide critical underpinnings for understanding the structural evolutions traps. In particular, well-exposed modern deformation systems can delineate with unparalleled clarity the ways in which thrust systems propagate laterally, fault segments link together, fold crests and limbs migrate and rotate in space and time, and fault geometries depend on material properties, pre-existing weaknesses, and topographic loading. Using deformed geomorphic markers, we propose to delineate along-strike changes in an active thrust fault geometry, and accommodation of displacement variations in a well-exposed fault zone. Our primary focus will be on faulted, folded, and rotated fluvial terraces in the Ostler fault zone in southern New Zealand. Along its 50-km length, this spectacularly well-exposed fault deforms regionally extensive glacial outwash surfaces and fluvial terraces of varying ages and known initial geometries that record the detailed evolution of this thrust system, define rates of deformation, and illustrate strain partitioning and variable styles of strain accommodation across this fault zone. Detailed images of the geometry, spatial variation, and temporal evolution of deformation in an active thrust system will add new impetus and insight to predictive models of thrust-fault-related deformation.

Burbank
UC Lawrence Livermore National Laboratory
SB050041
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.

Busby
Department of Interior
05HQAG0010
Geologic Mapping of the Central Sierran Frontal Fault System with Implications for the Tahoe Basin and the Carson-City Bridgeport Population Corridor
04/21/05-03/31/06
$29,246

This research will unravel the Neogene to Recent evolution of the Sierra Nevada—Basin and Range transition in the central Sierra Nevada. This segment of the Sierran range front lies within the Walker Lane, a complex system of dominantly right-lateral strike slip faults that accommodates ~20-25% of Pacific-North America plate motion. The range-front fault system in the central Sierra consists of a series of left stepping, *en echelon* escarpments, with focal plane mechanisms that suggest a major strike slip component on active normal faults. Field data from these active faults are notably lacking, however, and very little is known of the long-term history of slip on them. I propose a synergistic project involving a team of three Ph.D. students that will map Sierran range front faults between Carson Pass and Sonora Pass. In these projects, the students will map Sierran basement rocks, including plutonic and metamorphic rocks, to find kinematic indicators and distinctive features that can be used as piercing points across faults. They will divide previously undifferentiated Tertiary volcanic rocks by applying modern volcanic facies analysis and by mapping unconformity surfaces. Together with $^{40}Ar/^{39}Ar$ dating, this will allow the students to reconstruct the paleogeography and fault movement histories for Neogene time. They will map Quaternary deposits and, where appropriate, use GPS surveys to accurately measure active fault scarps and offset Quaternary features, such as streams, moraine crests and river terraces. They will become trained in digital mapping techniques using Hewlett Packard IPAQ unit with integrated GPS receivers and touch-sensitive screens for mapping geologic features onto geo-referenced base maps, including topographic maps, DOQQs and satellite images, using ARC GIS. The synergism of having three graduate students mapping and interpreting similar rocks and faults at the same time will be an enormous educational advantage.

Busby
National Science Foundation
EAR-1025779
Collaborative Research: Miocene Volcanism in the Sierra Nevada, California
03/01/2002-08/31/2005
$300,000

Volcanic and volcaniclastic rocks of the northern and central Sierra Nevada (California) represent a piece of the mid-Miocene volcanotectonic puzzle about which very little is known, relative to the rest of the western United States. This gap in our knowledge is crucial because the mid-Miocene was a time of fundamental tectonic change in the western United States (Atwater, 1970; Dickinson, 1997). This areally extensive "missing piece" of the mid-Miocene volcano tectonic puzzle is an important piece, because it lies in a tectonic setting that is transitional between subduction, Basin and Range, and hotspot settings. Recent work has suggested that a strong degree of coupling exists between the Pacific and North

American plates, and that this regime was established in mid-Miocene time. However, none of the dozens of recent regional tectonic papers consider the role of Sierran mid-Miocene volcanism in tectonic reconstructions, probably because too little is known of the volcanology, geochronology and structure of these rocks. The Sierran volcanic rocks are also of great interest in a process volcanological sense, because they are dominated by voluminous, widespread breccias, at least some of which appear to have been fragmented in the vents prior to eruption (Curtis, 1954). No one has attempted to determine the volcanological origin of these rocks for the past half century. Furthermore, new geochronologic and stratigraphic data from the Sierran breccias show that at least some of them are interstratified with a flood basalt that is the same age as the Columbia River Basalt group, referred to as the Lovejoy basalt (Wagner et al., 2000). Recent studies have documented similar enigmatic, voluminous breccias in flood basalts provinces of Greenland, Siberia, Africa and Antarctica. Can the volcanological origin of voluminous breccias be directly linked to flood basalt provinces, or do they represent a style of volcanism that can more generally be linked to extensional provinces, including extensional arcs?

We propose to establish a regional stratigraphic structural and geochronological framework for Miocene volcanic rocks of the northern to central Sierra Nevada, and at the same time reconstruct structural settings and volcanological processes. We will make detailed volcanic and sedimentary lithofacies maps, and use these to determine the nature and timing of synvolcanic faulting. We will use petrography, image analysis and Scanning Electron Microscope (SEM) imaging of the Sierran breccias to study and quantify clast and matrix types, morphologies, dimensions and fragmentation styles (brittle, ductile, transitional), and compare the results with published examples of volcanic breccias of all plausible origins. We will carry out preliminary geochemical analysis of representative suites by XRF (including all samples to be dated), and also compare compositions of clasts with matrices in the breccias. We will sample for $^{40}Ar/^{39}Ar$ age dating from stratigraphic successions containing at least three or four different datable units, to test for geological consistency in our age data, and analyze single mineral grains (total fusions) as well as performing incremental step heating experiments.

This work is divided into two areas. North of Lake Tahoe, we will target six recently-mapped quadrangles containing Lovejoy basalt, with the goal of making a tectonic reconstruction for Mid-Miocene time. South of Lake Tahoe, we propose to carry out a modern process volcanological study of voluminous breccias that were erupted from at least a dozen vents on the present-day Sierran crest, and flowed westward into the present-day foothills. Busby will coordinate the project, collaborating/supervising field studies in both areas with all other workers. Skilling will supervise a master's student's detailed study of vent-related breccias south of Lake Tahoe, co-supervise a postdoctoral fellow of Busby's, who will study proximal-to-distal variation in the breccias south of Lake Tahoe, and consult with Busby north of Tahoe. Gans will co-supervise a PhD student of Busby's who will work north of Lake Tahoe, and Gans will perform the $^{40}Ar/^{39}Ar$ analyses for the entire project.

Busby
Department of Interior
06HQAG0061
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

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. 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, in order to compare and contrast them with those of our proposed style I.

Geodetic GPS studies indicate that the Walker Lane accommodates ~20-25% of Pacific-North America plate motion. 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 range-front faults of the Sierra Nevada. 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. The proposed work is important for understanding the geology, neotectonics, and seisimic hazards posed by the central Sierra Nevada range front faults, where there have been recent earthquake swarms.

Busby
UC Mexus
SB060046
Exotic vs. Fringing Arc Models: Implications for the Growth of Continents
07/01/05-12/31/07
$15,251

The western margin of Mexico is ideally suited for testing two opposing models for the growth of continents along convergent margins. In the first model, the continent grows through accretion of exotic island arcs by the consumption of entire ocean basins at multiple subduction zones, with varying polarities. In the second model, protracted extensional processes in the upper plate of a subduction zone produce numerous arc-related basins, some rifted off the continental margin and others formed of new oceanic lithosphere; these continent-fringing basins become filled with detritus derived from arcs or the continent margin, and later become accreted to the edge of the continent during compressional, transpressional or transtensional phases of subduction. In some cases, renewed upper plate extension rifts these terranes off the continental margin once more, in a kind of "yo-yo" tectonics along the continental margin.

These two opposing models have been proposed for the origin of the Guerrero Terrane in mainland Mexico, and the Alisitos-Vizcaino Terranes in the Baja California Peninsula, and we propose to test these models there. These terranes are significant for composing about a third of Mexico (Figure 1), a country that was tectonically assembled in relatively recent geologic time (largely Late Paleozoic to Mesozoic). Some authors have suggested that the Alisitos-Guerrero terranes represent an arc that was accreted to nuclear Mexico in Late Cretaceous time via a subduction system that dipped westward, closing an entire oceanic basin located between the arc and the continent (Tardy et al, 1994; Lapierre, et. al., 1992; Dickinson and Lawton, 2001). However, other authors have suggested that the Guerrero and Alisitos terranes represent one or more marginal arcs that fringed the continent (Campa and Ramirez, 1979; Centeno-Garcia et al., 1993; Busby et al., 1998; Centeno-Garcia et al., 2003; Busby, 2004).

We request support that will allow us to take advantage of an unusual opportunity to foster collaboration between the University of California and the National University of Mexico. Elena Centeno-Garcia is a professor at UNAM and a member of the Mexican National Academy of Sciences. She got her PhD at the University of Arizona in 1994, working on the geology and geochemistry of the terranes of Mexico. Professor Centeno-Garcia is at UC Santa Barbara for the 2004-2005 academic year on a sabbatical funded by UNAM. Her sabbatical host, Cathy Busby, is a Full Professor at UCSB who has worked in Baja California for 20 years. For many years, Elena and Cathy have been working independently on either side of the Gulf of California, studying rocks that should be examined as a unit because they share many characteristics. The fact that Elena and Cathy are both leaders in the field of arc collision zones is reflected in the fact that both will be keynote speakers at a prestigious Penrose Conference on the topic in October, 2005 (see announcement in GSA Today, May 2005).

This year we have finally had the opportunity to begin working together. During winter quarter 2005, we team taught a graduate course on the geology of Mexico at UCSB, and followed that with a short course for graduate students at UNAM at the end of the quarter. Then, over spring break 2005, we took the combined group of Mexican and American students on a ten-day field trip through southern Mexico, on funds we raised jointly from industry and university sources. This joint UCSB-UNAM course is the start of a strong collaborative relationship between the University of California and the National Autonomous University of Mexico. Our collaboration is also an unusual opportunity to provide female and minority students with strong role models. The support we request here will allow us to do enough preliminary field and lab work to frame strong joint proposals to the National Science Foundation or other agencies.

Our collaboration will extend to the Autonomous University of Guerrero to include Professor Martin Guerrero-Suastegui. He got his Ph D. at Memorial University in Saint Johns Newfoundland in 2004, working on the Teloloapan Terrane of the Guerrero Composite Terrane (Figure 1). Martin participated in Cathy and Elena's short course at UNAM at the end of winter quarter, and led the combined UCSB-UNAM class through his PhD area for a day. His participation in the project is crucial for reconstructing the stratigraphic and tectonic evolution of the Guerrero-Alisitos terranes. Martin's participation also will help to strength international collaboration in research activities for the University of Guerrero.

Clark, Leifer, Luyendyk, Washburn
University of Alaska, Fairbanks
UAF-05-0140
Survival of Methane in Rising Marine Bubble Plumes: Testing a Critical Assumption of the Clathrate Gun Hypothesis-
03/01/05-02/28/07
$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
San Gabriel Spreading Area Tracer Study and Rio Hondo-South Montebello Well#5 Tracer Study
01/01/02-12/31/06
$116,914

In June 2005 a second sulfur hexafluoride (SF_6) experiment was initiated to examine travel times to the lower and upper screen intervals at well #200061. During the first experiment, tracer appeared at this well after 8 weeks. The experiment was designed to test the hypothesis that the short travel time reflected the arrival of tracer at the upper section of the screen interval and that the travel time to the lower section is longer than 8 weeks. Therefore, by installing a packer that isolates the upper and lower sections, travel times to the lower section would be longer. This hypothesis was tested performing a second tracers experiment.

The procedures used during the second experiment were identical to those used during the initial 2003 experiment. The only differences were the timing of the tracer release and the number of spreading basins tagged with SF_6. During the second experiment, tracer was injected into ponds 1-5 at the end of the rainy season from June 14 to 23, 2005. While all of these ponds were full and actively recharging the groundwater system, ponds 6-10 were dry. SF_6 concentrations within the recharge basins were variable and approximately the same as in 2003, ranging between about 10 and 90 pmol/l. The timing of the tracer release coincided with the placement of the packer in well #200061. Because of numerous problems with installing the packer, the start date was three to four months later than originally planned.

Groundwater tracer concentrations were monitored from two production wells (#200061 and #200065) and four monitoring wells (#100830, #100834, #100904, and #100906). Travel times were determined to four of these wells (#100830, #100834, #200061, and #200065) during the 2003 experiment. Prior to the June tracer release, SF_6 concentrations at these wells were below the detection limit, showing that the plume from the first experiment had passed. After the release, well samples were collected every two to four weeks. Samples from both above and below the packer in #200061 were included.

With the exception of well #200061, travel times to wells determined during the second experiment were consistent with 2003 results (Fig. 1). Very short travel times were found to the relatively shallow monitoring wells surrounding the recharge basins. The travel time to well #200061 was significantly longer, increasing from 8 weeks in 2003 to 26 weeks in 2005. It is important to note that production from well #200061 was drawing water from only below the packer. Flow to the upper section was following the “natural” gradient near the spreading basins. In fact, the 26 week arrival time to the upper section is very similar to the expected value, based on depth, for monitoring wells established during the first experiment (Fig. 1). The increase from 8 to 26 weeks for the lower sections supports our hypothesis and the primary conclusion from the 2003 experiment that within 500 feet of a spreading pond depth is the primarily factoring controlling the travel time.

Clark, Leifer, Valentine
UC Energy Institute
SB050110
Fate of Dissolved Hydrocarbon Down Current of the Coal Oil Point Seep Field: The Indirect Atmospheric Source
07/01/05-06/30/08
$31,100

Natural marine hydrocarbon seeps are important sources of oil, tar, methane, and other hydrocarbons including reactive organic gases (ROGs) to the regional and global environments. Quantification of seepage rates is needed for calculating regional pollution inventories and to better estimate global methane sources from natural seepage. One of the world's largest and best studied seep regions, the Coal Oil Point (COP) seep field, is located along the northern margin of the Santa Barbara Channel about 15 kilometers from the City of Santa Barbara. Through numerous studies supported by UCEI and other funding agencies, the UCSB seep group has documented the direct flux of gas to the atmosphere from bursting bubbles, oil emission rates, temporal and spatial variability of flux rates, and the dynamics of bubble plume processes which effect the dissolution rate rising seep bubbles. An important question that has yet to be studied is the fate and transport of the hydrocarbon gases that dissolve during the bubbles' transit from the seafloor to the surface. Earlier surveys near COP indicate that about half of the gas emitted from the seafloor vents dissolves, creating a large mixed-gas plume. Methane, ethane, and propane concentrations within this plume were more than three orders of magnitude greater than atmospheric equilibrium concentrations in some locations. These earlier measurements suggest that the dissolved plume may be a significant source of seep gases to the atmosphere. In this study, we propose to quantify the air-sea gas transfer rate from the dissolved gas plume to determine the magnitude of this indirect hydrocarbon source. As part of the field surveys, we will determine the stable isotope composition (δ13C) of methane, ethane, and propane down current of the seafloor vents to estimate the loss rate due to microbial oxidation. Preliminary air pollution surveys along the coast of Santa Barbara show that this source may be comparable to the direct gas flux for some seeps. They have also shown that large natural sources occur away from the seep field. We hypothesize that these sources are from the indirect flux that adds a previously unknown spatial component to the natural seep source. Finally, indirect exchange provides a mechanism by which methane from bubbles that dissolve below thesea surface can contribute to atmospheric budgets.

Clark
National Science Foundation
OCE-0550203
Collaborative Research: A Three-Dimensional, Subseafloor, IODP Observatory Network in the Northeastern Pacific Ocean, and Initiation of Large-Scale, Cross-Hole Experiments
02/01/06-01/31/07
$89,100

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.

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 undergradute 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.

Clark
Big Bear Area Regional Waste Water Agency
01956
Green Spot Groundwater Tracer Experiment
07/01/05-06/30/06
$40,327

Ground water travel times between recharge sites and production wells are important criteria for the permitting of artificial recharge operations that use recycled (reclaimed) wastewater as source water. As part of the site evaluation for the potential artificial recharge operation in Big Bear Valley, CA, deliberate gas tracer experiments using sulfur hexafluoride (SF_6) were conducing during the spring and summer 2004 from two pilot basins, Van Dusen and Green Spot. These experiments were unsuccessful because the gas tracer was lost from the percolating water to soil air beneath the pilot basins prior to crossing the water table. A second experiment was conducted at the Green Spot location between July 2005 and March 2006. During the second experiment, tracer was injected into the groundwater via monitoring wells drilled within the spreading basin. Groundwater samples were collected down gradient to determine groundwater travel times.

Clark
UC Davis
K011552-04
Stockton Deep Water Ship Channel Tracer Experiment
06/01/05-06/30/06
$50,714

A tracer experiment using Sulfur Hexafluoride (SF6). SF6 can be detected at concentrations as low as parts per trillion, and is therefore detectable in the river and through the main study reach in the Deep Water Ship Channel (DWSC) and beyond. It is a highly specialized technique, and Clark and Ho both have extensive experience with its use. Ho has devised a system for onboard sampling and detection, which enables measurements to be taken every 2 minutes from a moving boat, as opposed to sample collection and subsequent lab analysis. These data will provide the ultimate comparison field test for the three-dimensional model that we are developing. Drs Clark and Ho will perform the SF6 injection, and then perform the field tracking and analysis. Staff from UCD will work with Clark and Ho to interpret the tracer data by providing the necessary flow and profile data. The tracer study will provide transport and dilution data, that will make it possible to definitively know if the models that are produced are correct.

Clark
UC-IGPP
05-GS-024
The Importance of Groundwater Weathering in the Upper South Fork Kern River Catchment
10/01/04-09/30/05
$23,500

Chemical weathering of silicates consumes atmospheric CO_2, an important greenhouse gas, and releases ecologically important nutrients and trace elements. Most field studies have estimated chemical weathering rates using mass balance calculations of solute fluxes into and out of small watersheds. This method for calculating chemical weathering rates determines the total amount of weathering occurring within a basin without identifying the relative strengths of the different reservoirs such as the soil and shallow groundwater that contribute to the solute flux.

We are interested in understanding the relative contributions from the groundwater zone to the overall weathering flux. In order to determine this we need to know the rates of chemical weathering within groundwater and the "age" spectrum of groundwater that feeds streams during baseflow. We developed a new approach for quantifying chemical weathering within the shallow groundwater in Sagehen Basin (Nevada County CA) using prior IGPP-LLNL support. Fundamental to our mehod was the merging of solute mass balance calculations with geochemical groundwater dating techniques. We determined that concentrations of the major cations increased with groundwater age (Rademacher et al. 2001). For instance, calcium concentrations increased by more than a factor of three during the first 40 yrs of groundwater flow. This increase is indicative of a chemically evolving groundwater system; water with longer residence times has more time to interact with the surrounding material and weather primary minerals. Additionally, we determined that baseflow in Sagehen Creek was composed of relatively old groundwater by comparing the geochemical fingerprint of the creek with the fingerprint of the spring water which changed with groundwater age (Rademacher et al., 2004). Compositionally, the creek during baseflow was most similar to springs that had geochemical ages of about 25 yrs. This surprising result indicates that a relatively large groundwater system exists in Sagehen Basin and that chemical weathering within the shallow ground contributes significantly to the solute flux. Furthermore, it implies that stream solute chemistry should be partially determined by the size of the groundwater system. Streams emanating from larger basins with deeper sediments should contain older groundwater and therefore, these streams should have higher cation concentrations than streams from smaller basins. Additionally, the result indicates that there should be a significant lag between changes in stream chemistry and land use changes.

Using our geochemical field approach, we propose to determine chemical weathering rates in the groundwater zone of the Upper South Fork Kern River watershed (Inyo and Tulare Counties, CA). Our primary goals are 1) to determine if groundwater chemically evolves at similar rates throughout the Sierras and 2) to determine if relatively old groundwater supplies late summer baseflow elsewhere in the Sierras as it does in Sagehen basin. These results will add a perspective to the surprising Sagehen Basin results and should lead to a better model for the hydrochemistry of watersheds in the Sierra Nevada.

Dykstra/Meiburg
University of Aberdeen (Scotland)
SB060035
UCSB Subcontract for ‘Stratigraphic Development of Large Scale Turbidite Slope Systems: Rules for Reservoir Modeling and Reservoir Distribution
05/01/05-04/30/08
$406.850

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
Neogene Evolution of the Sonoral Margin: The Transition from Backarc Extension
01/01/03-12/31/06
$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 a 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
Miocene stratigraphy of the Gravel Hills-Mud Hills-northern Calicvo Mts., central Mojave Desert, CA
09/01/05-12/31/06
$40,825

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 a Ph.D. thesis 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.

Goetz
Navy
N6921803 IPA0001
Bioremediation and Microbiology Technical Support
10/01/02-10/30/05
$467,160

Biodegradation of petroleum contaminated soil and water. As follow-on to work previously conducted by the Navy, the contractor shall produce technical reports, presentations, and articles related to the remediation of petroleum-contaminated soils, water, and sludges. In addition, the contractor shall conduct studies on the fate and transport of hydrocarbons and hydrocarbon degradation products.

Solid Waste Management: Navy and Marine Corps solid waste reduction and recycling programs are ongoing efforts to divert solid waste. In coordination with facility personnel, NFESC is tasked with designing and implementing solid waste management programs and providing technical support during regulatory negotiations and oversight. The contractor shall support continuing efforts to reduce and treat solid waste through evaluation of operations and review of permit requirements.

As part of this effort, the contractor shall produce a chapter on composting for a Navy sponsored solid waste management practices (SWMP) guide. The guide will aid installations in reducing waste and waste management costs. The guide will discuss installation generated waste streams and discuss how to compost organic waste. The chapter will describe the science of composting, the benefits of composting, composting techniques composting equipment, test procedures, composting feed materials, composting standards, disposal of the finished product, vector and pathogen reduction, manpower requirements, composting references and web site information. The feasibility of composting on-site vs. other locations such as a local private or municipal composting facility should be compared. Pictures and diagrams shall be used to illustrate the chapter.

Long-term Monitoring and Maintenance Plan (LTMMP), Former Naval Air Station Barbers Point, Hawaii. The remedial investigation (RI) conducted in conjunction with the BRAC ordered closure of NAS Barbers Point included ~ 35 acres of land that the Navy has retained. The results of this investigation are summarized below. These results are relevant to the Long-Term Monitoring and Maintenance Plan (LTMMP) because contaminated soil from other areas of the base were excavated and used to cap the area known as the monofill. As a result, the Navy is required to monitor and maintain the landfill cap for thirty years.

The Navy used the monofill for the disposal of biosolids that were air-dried on-site. The biosolids contained diesel range hydrocarbons and there is some evidence that asbestos may have been disposed at this site. However, the bulk of the asbestos was probably disposed in the adjacent solid waste landfill. Even though sludge was been disposed at this site for more than 20 years, the RI did not detect hydrocarbons or elevated metals in the subsurface unconfined aquifer. Furthermore, the ground water is aerobic which suggests that little or no migration of organic matter has occurred over the intervening years. Small quantities of methane were detected in some soil gas samples. Since microbial degradation of the methane occurs in the near surface aerobic soils, the concentration of vented methane is probably less than that detected in the soil gas samples.

As required by 40 CFR 503, sewage sludge disposed of at the monofill was analyzed quarterly. A review of the years 1993-1996 shows a few samples with low levels of toluene, ethylbenzene, and/or xylenes and none with benzene, PCBs or common chlorinated hydrocarbons including PCE, TCE, and chloroform. chlordane, dieldrin, DDE, and DDT were reported in 2-3 samples at ppb concentrations and PAHs (primarily; naphthalene, phenanthrene, fluorene, anthracene, pyrene) were often present either alone or in various combinations along with phthalate esters. These results are consistent with the soil gas analyses that detected only methane. Metals (primarily; Al, Zn, Hg, Cd, Cr, Cu, Pb, Ni, Ag) were present in most samples.

Since the RI indicates little or no migration of contaminants from any of four potentially problematic areas, the question becomes what are the appropriate monitoring requirements. The contractor shall work with NFESC and PWC Pearl Harbor to review applicable documents, identify appropriate analytical methods and design a realistic monitoring plan. Meetings with the PACDIV Remedial Action Contractor and Hawaii Department of Health (DOH) might be required to support the contractor's technical review and recommendations.

Biocorrosion. In collaboration with the Oceans Engineering Group at NFESC, the contractor shall investigate the role of microbial biofilms in the corrosion of metals. These studies shall be designed to determine if bacterial growth on metal surfaces in seawater enhances or retards corrosion and to what extent. The contractor shall produce a report documenting the findings of this investigation.

Environmental Forensics. The contractor shall work with the Technical Transfer Group in the Environmental Restoration Division at NFESC to develop methods for better determining the source and fate of environmental contaminants. The results shall be presented in a series of lectures in conjunction with the International Society for Environmental Forensics.

Hazardous Waste Treatment; Bioreactors. In collaboration with PWC Pearl Harbor (Code 300) NFESC is working to implement a biological treatment system for fuel tank residuals. Laboratory and pilot scale tests have shown that diluted oily wastes mixed with inorganic and organic nutrients stimulate rapid hydrocarbon degradation by bacteria already present in the waste. At PWC Pearl Harbor, an existing 10,000-gallon storage tank was converted to use as a sequencing bioreactor using off the shelf equipment and monitors to create a full-scale treatment system. The system is designed to operate as a zero-discharge system with clean effluent going to the sewage system or recycled through the bioreactor. Biomass that accumulates in the reactor is periodically harvested and composted at the PWC operated composting facility. Initially, the Navy will concentrate on treating fuel tank residuals. Once field tests are complete, additional waste streams could be added to include oily sludge from sewage lift stations, ship oily waste, used oil waste tank bottoms, and fuel tank bottoms.

Hacker
National Science Foundation
EAR-0215641
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
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
Woods Hole Oceanographic Institution
A100169
Contraints on the Genesis of Continental Crust via Arc Magmatism: Geology, Geochemistry, Structure and Physical Properties of the Talkeetna Arc Crustal Section, South Central Alaska
08/01/00-07/31/06
$298,325

This proposal is for a multi-year, interdisciplinary study of the exposed crustal section of the Talkeetna island arc to address the rate and mechanism of continental growth at convergent margins. The Talkeetna arc section, particularly in the Nelchina-Tonsina region, is a crustal section through an accreted, Jurassic subduction-related magmatic arc, from volcanic, volcaniclastic and sedimentary rocks at the top to residual mantle peridotites at the base. Detailed studies of exposed, island arc sections can provide a crucial link between geophysical observations and geochemical studies of volcanic rocks in active arcs. In the same way that ophiolite studies have provided an ideal counterpoint to both marine geophysics and analysis of mid-ocean ridge basalts in developing a complete picture of crustal accretion at oceanic spreading ridges, studies of arc sections will be essential to progress in understanding arc magmatism and crustal genesis over the coming decade.
Our study addresses a key question regarding arc processes: What is the rate and mechanism of continental growth at convergent margins? Arc crust is basaltic. Continental crust is formed mainly in arcs. Continental crust is andesitic. How can these three ideas be reconciled? Clearly, although each of these points is open to question, research funded by this grant will mainly address the first one. However,

in our proposed study we will also determine compositional layering of the arc crust, and constrain proposed scenarios for lower crustal delamination during and after arc magmatism. Most importantly, work on the Talkeetna section can provide crucial constraints on the composition and timing of accretion of the middle and lower arc crust, which are generally not exposed in active arcs. Evidence from rare plutonic exposures in the Aleutian and Izu Bonin arcs indicates that different processes or different primary magmas may produce intrusive and extrusive rocks, so that inversion of volcanic rock compositions is not sufficient to determine the bulk crustal composition, nor the nature of primary melts passing from the mantle into the lower crust.

In our proposed study, we will address various aspects of crustal genesis in a practical way, applying a variety of analytical techniques. Our research goals are to (1) make an improved geological map and use a fully two -dimensional approach to better constrain the relative proportions of the different rock types in the Talkeetna arc crustal section; (2) determine the deformation history of lower crustal rocks, identify and date faults along which section may be missing or repeated, , make thermobarometric estimates from mineral compositions, and thereby better constrain how much of the section is missing and how to interpolate the data for the rocks that are exposed; (3) make extensive measurements of physical properties of rock samples for comparison with the growing database on seismic refraction and reflection in arcs; (4) conduct detailed investigations of residual mantle harzburgites and igneous ultramafic rocks just below the base of the gabbroic crust in order to determine the mode of melt transport from the mantle into the crust, and determine the relative importance of ultramafic "cumulates"; (5) conduct major trace and isotopic analysis on a comprehensive suite of samples from all the igneous rocks in the section, together with extensive new geochronology studies, to delineate how many liquid lines of descent are represented in the arc crustal section, and which are most volumetrically important; (6) use petrological and trace element modeling techniques to quantify the possible proportions of different rock types, for comparison with the proportions of rock compositions determined by geologic mapping, providing a further constraint on the bulk composition of the arc crust; and (7) to look at the P-T-t history of the lower crust, in order to constrain Moho temperatures in active arcs, and to provide constraints on the density and viscosity of arc lower crust during and after magmatism.

Hacker
National Science Foundation
EAR-0309995
Collaborative Research: Direct Observation of Depth Variation in Fault Zone ...
01/15/04-12/31/06
$116,316

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.

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 timingrelationships, 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.

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 earthscience journals and formal presentations at the GSA and AGU national conventions and joint AGU-EGS-EUG meetings in Europe.

Hacker
National Science Foundation
EAR-0545399
Collaborative Research: Earthscope Integrated Investigation of Cascadia Subduction Zone Tremor, Structure and Process
01/01/06-12/31/09
$138,744

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 downgoing 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.

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.

Hacker
Mattinson
National Science Foundation
EAR-0510453
The Assembly of UHP Terranes: Was the Western Gneiss Region Built by Sequential or Repeated (Ultra) High-Pressure Events?
07/01/05-06/30/07
$328,178

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.

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.

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-0632774
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.

Ji
Department of Interior
05HQGR0173
Collaborative Research with University of California Santa Barbara and USGS: Real-time Global Earthquake Characterization
10/01/05-9/30/06
$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.

Leifer
Boles
Luyendyk
UC Energy Institute
SB050040
Oil in the ocean: Contribution from natural seeps
07/01/04-08/30/06
$35,000

Oil enters the ocean from both natural and anthropogenic sources, causing environmental and ecological damage. Global estimate of marine oil emissions from natural hydrocarbon seeps are significant, ~0.6 Megatons yr-1, while accidental spills contribute just 0.1 Megatons yr-1 (*NRC* 2003). The Santa Barbara Channel, CA hosts some of the largest and best-studied seeps globally, with seepage estimated at 100 - 600 bbl dy-1 (*Clester et al.* 2003) based on a surface boom capture study and aerial overflights. Values were extrapolated to the entire seep field using sonar-quantified gas fluxes in the study area and entire field and assuming a field-wide oil/gas ratio. Although widely quoted, significant uncertainties exist, particularly given variability of seepage.

For example, gas seepage varies with tides - ~10% (*Boles et al.* 2001) - and swell (*Leifer & Boles* 2003a). Using a UCEI-funded 3-turbine seep-tent network, *Leifer & Boles* (2003a) discovered that gas seepage varied significantly, both temporally and spatially, due to subsurface interactions between gas, oil, and tar (*Leifer & Boles* 2003b; *Leifer et al.* 2003). These results were leveraged into a Petroleum Research Fund (PRF) grant for a 40-tent gas seepage monitoring network. Given oil's range of physical properties (from n-alkanes to tar), greater variability thnan gas is likely. Thus quantification of temporal and spatial variability is critical to assessing oil fluxes.

Aerial surface slick observations often provide the first estimates for leaking oil from pipelines, caissons, shipwrecks, etc., as well as a critical tool to monitor during clean-up. However, largely unknown water-column processes can cause seabed oil emissions and surface slick estimates to be widely divergent. Only for certain conditions does oil escaping the seabed reach the sea surface. Thus mitigation strategies depend upon the oil's fate.

We propose using two seabed oil-capture seep-tents to measure temporal and spatial oil flux distributions in the COP Field at sites studied in pioneering flux estimates by *Allen et al.* (1973). Seabed oil flux variability will be quantified and related to surface and slick observations to identify forcing parameters (tides, water temperature, currents, etc.) affecting oil seepage and water-column transit. This research provides :

1. Determination of process(es) most important to oil transport from seabed to sea surface.
2. Description of seabed oil-flux spatial and temporal variability (including confidence limits).
3. Measurement of oil to gas ratios as a function of oil and gas fluxes.

Results are of importance to decision makers, industry, and scientists include :

1. Better estimation of seabed oil flux emissions from observations of surface slicks.
2. Identification of forcing factors driving oil seepage emission variability.
3. Assessment of feasibility of permanent oil capture tents.
4. Improved prediction of the fate of oil emitted from seeps, wrecks, pipelines, or leaking oil wells.

This project meshes well with other seep projects supported by UCEI, PRF, US Mineral Management Service, and California Department of Fish and Game, including oil slick sampling, bubble flux measurements, temporal and spatial variations of gas seepage using turbine seep-tents, oil seepage from leaking oil cassions, and gas-flux surveys with a direct capture buoy.

Luyendyk
Leifer
UC Energy Institute
SB050109
Oil in the Ocean: Field and Numerical studies of Oil Slicks in the Coastal Waters of the Coal Oil Point Marine Seep Field
07/01/05-06/30/07
$30,545

Predicting the fate of oil in the ocean from accidental spills and natural sources is a significant concern across a broad stretch of society, from citizens to government agencies, to advocacy groups protecting delicate coastal habitat. Both large spills, which engender intense public scrutiny, and chronic, small-scale spills (natural or otherwise), can cause significant environmental damage. The numerous oil components have varied chemical and physical properties–including toxicities, and thus different impacts. Predicting these impacts, and thus the best response strategy, requires understanding the oil's advection, dispersion, and chemical evolution.

Oil and tar balls continually wash up on the shores of Santa Barbara Channel (SBC). Although offshore oil production is popularly assumed to cause oil and tar on SBC beaches, natural hydrocarbon seeps are an important and possibly dominant source. The greatest tar accumulations are near Coal Oil Point (COP) and the protected Snowy Plover Reserve. Here, the oil and tar most likely arise from natural sources in the offshore COP seep field and are transported to the shore by currents and winds. Despite the obvious interest, the specific sources of beach tar and oil remain unknown. As a case in point, during Jan. 2005 thousands of oil-coated sea birds turned up on beaches from Summerland nearly to Los Angeles. Despite intense efforts over several weeks, the oil source remains unclear. In our view, lack of knowledge on the fate of oil in the ocean hampered investigators reaching conclusions on the source(s).

Laboratory studies can help improve marine oil spill prediction models, but many spill processes are not amenable to laboratory simulation. Field data clearly are critical but there is a paucity of such data for marine oil slicks, particularly during the initial phases of a spill. The continuous oil seepage from the easily accessible COP seep field is an ideal and unique natural laboratory to study oil spill processes.

We propose studying the initial oil slick processes using an improved slick tracking method and a CATamaran DRUM Slick sampler (CATDRUMS). These processes include slick advection, mixing between slicks, evaporation, and lateral spreading. Data will be compared with numerical model predictions of slick trajectories to improve model accuracy. Studies will cover a range of air and sea conditions and processes will be related to winds and currents. This proposed research is a continuation of a previous, UCEI-funded project during which CATDRUMS and the slick tracking methodology were developed and field-tested. Field data were compared with numerical modeling studies of slick trajectories. The proposed research will study several slick processes discovered during these missions, particularly significant discrepancies found between predicted and observed slick trajectories. This study includes further improvements in CATDRUMS, additional surveys, and improvements in numerical slick modeling.

Given the widespread interest in oil in the ocean, we have developed active collaborations with many interested government agencies and scientists. This study will be in collaboration with the US Geological Survey, the Calif. Dept. of Conserv., the Calif. Dept. of Fish and Game, Oil Spill Prevention and Response (OSPR), and the National Oceanic and Atmospheric Administration, Hazardous Materials Laboratory. Collaboration also includes scientists with several funded projects: Libe Washburn (LTER CODAR surface current measurement system), Carter Ohlmann (surface current drifters), and Chris Reddy from Woods Hole Oceanographic Institution. The previous research study was leveraged into support from US Geological Survey, OSPR, and UCSB. It will be leveraged further with future proposals to NOAA (through the Coastal Response Research Center), and the US Coast Guard.

Luyendyk
Wilson
National Science Foundation
OPP/ANT-0088143
Collaborative Research: Antarctic Cretaceous-Cenozoic Climate, Glaciation
09/15/01-08/31/07
$470,720 and $7,500 REU supplement and Workshop $5,675

The Ross Embayment, including the Ross Sea rift, separates East and West Antarctica today. The Ross Sea rift and western Marie Byrd Land (wMBL) are part of the West Antarctic rift system. It is widely accepted that this region is undergoing active deformation, but the rates and causes of deformation are essentially unknown. Crustal motions may be occurring across the Ross Sea rift today. Crustal uplift could be occurring in wMBL due to isostatic rebound following the last glacial age. If tectonic motion is occurring in the Embayment this could greatly influence global plate circuit calculations. Post glacial rebound in wMBL would depend on the configuration of the ice sheet during the Last Glacial Maximum and when this occurred. The main question is whether or not the ice sheet collapsed in mid-Holocene time.

In December 1998 we installed three continuous and autonomous GPS stations on outcrops in wMBL, in the Rockefeller, Phillips, and Clark Mountains. Results from three years of data collection indicate essentially no extension between McMurdo station (MBL4) and the network. The results show an overall length rate of –0.7±3.5 mm/yr between MCM4 and the wMBL network. With additional years of measurements we should be able to discriminate whether this rate is near zero or not to about 1 mm/yr. We also expect to detect strain gradients within wMBL. The network also suggests a dome of uplift centered near the Rockefeller Mountains, with the maximum rate being in the Rockefeller Mountains of 12±8 mm/yr. This is consistent with proposed post-glacial rebound for the region. With over seven years of data we expect to determine crustal strain rates to an accuracy of one mm/yr horizontal and 2 mm/yr vertical. The strain data from wMBL and the Transantarctic Mountains will enable us to construct models for tectonic extension and glacial rebound in the West Antarctic rift.

We propose to continue operation of the three stations in wMBL for another four year period. These stations will be upgraded with modern receivers and satellite data downloading when such downloading becomes feasible. We will add an additional continuous station during the 2002/2003 season in the Transantarctic Mountains near the South Pole on Mount Howe. We will install a second new continuous station at Mount Coates in the Transantarctic Mountains 2003/2004 season at the location of the previously operational continuous station. This will create a network that is geometrically ideal for understanding the orientation of maximum extension across the Ross Embayment and will clarify the pattern of postglacial rebound. Should Mount Coates be re-established by Carol Raymond we will install that station at another location in the Transantarctic Mountains.

This project is collaborative with other geodetic investigations in Antarctica and we will freely share our data. This includes networks led by Carol Raymond of JPL-Caltech in the Transantarctic Mountains, the WAGN (Marie Byrd Land) project led by Ian Dalziel, at University of Texas at Austin, and the Transantarctic GPS project led by Larry Hothem of the USGS. We will also collaborate with Erik Ivins at JPL, who is an expert on postglacial rebound. Our team brings together experts in wMBL geology and tectonics, tectonic geodesy, and lithospheric deformation.

Mattinson
National Science Foundation
EAR-0549672
Collaborative Research: Development of Improved Zircon Standards for SIMS and LA-ICP-MS-U-Pb Geochronology using CAT-TIMS Pre-Treatment
06/15/06-05/31/07
$26,708

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.

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 Eximer LA-ICPMS facilities; and 4) distribute the results, and pre-treated standards to the geochronological community.

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.

Niemi
National Science Foundation
EAR-0310252
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.

Olsen
University of California Los Alamos National Laboratory
SBB-014A
Fully Non-Linear Inversion of Dynamic Earthquake Rupture Propagation
11/01/02-10/31/05
$94,093

Numerical simulation codes (*Olsen et al*., 2002) are now sufficiently sophisticated to estimate ground motions in large urban areas by including large-scale, state-of-the-art three-dimensional models of sedimentary basins (*Olsen et al*., 1995) using high-performance computing. However, a limiting factor in the accuracy of the predicted ground motions, even for the low frequencies, is accurate knowledge about the complexity of earthquake rupture. *Olsen et al*. (1997) showed that inclusion of the heterogeneity in rupture propagation is critical for accurate prediction of the resulting ground motion around the fault which is an important part of seismic hazard assessments. Another critical research area where accurate knowledge of rupture parameters is essential, earthquake prediction, is maybe the most important of them all. If we can further our understanding of the conditions under which earthquakes initiate, propagate, and arrest, as well as their variations in stress and friction, we may be able to predict the occurrence of future damaging events and thereby mitigate the loss of lives and property.

The conventional procedure to infer information about the rupture history of large earthquakes is a linear inversion for the slip history on the fault by matching recorded and synthetic accelerograms (*Wald and Heaton*, 1994). Such inversion has traditionally been carried out kinematically, which has some important limitations, in particular unphysical constraints on the rupture velocity and omitting dynamic rupture effects from the normal-stress interaction with the free surface. For example, the latter effects can play a significant role for earthquakes on shallow faults or ruptures breaking the surface (*Oglesby et al*., 1998; *Gottschammer and Olsen*, 2001), including earlier arrival times caused by super-shear rupture velocities and an increase of peak horizontal motions by up to about a factor of three. Therefore, when ignoring the dynamics, slip inversion may produce biased information about the rupture.

A more physically correct inversion would therefore take into account the dynamics of the rupture, i.e., the stress, strength, and friction parameters. However, such inversion is highly complicated due to the strong nonlinearity of the dynamic problem, as demonstrated by *Peyrat et al*. (2001) who inverted for the dynamic rupture history of the 1992 M7.3 Landers, California, earthquake using a trial-and-error method. The results by *Peyrat et al*. (2001) showed that the radiated waves are highly sensitive to the distribution of stress and friction parameters on the fault, an essential requirement for the inversion to work. Here, we attempt to carry results by *Peyrat et al*. (2001) to a new level using a fully systematic, nonlinear inversion method.

Polet
National Science Foundation
EAR-0538263
The Seismology of Shallow Intraplate Subduction Earthquakes: From Outer Risa to Interface
01/01/06-12/31/06
$106,961

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 et al. (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 rise events. 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 spectral analysis 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 fabric resulting 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 weak zones 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.

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
Department of Interior
05HQGR0003
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
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

Modern day broadband networks and real-time data gathering allow us to monitor the Earth in greater detail and over a much wider bandwidth. Recent discoveries of hitherto unknown seismic processes and the observation of slow precursors to large earthquakes suggest that it is very important to extend the current detection and location capabilities to cover a much wider spectrum. We therefore propose to develop and a apply detection and location algorithm for seismic events that uses data at long periods, with the potential of detecting both regular seismic events and serve as a backup to traditional methods as well as more anomalous events that are currently not detected routinely.

We have developed a very simple but powerful method of locating earthquakes using surface waves. It consists of a continuous progressive conversion of timeseries 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. 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 timesteps and the period range.

Our test results, based on a few stations and simple 1-D velocity structures already show that the method can detect and locate earthquakes with magnitudes larger than of 5.5 on a global scale, and down to magnitude 4 at a local scale. We expect that these thresholds will be extended downward as we use more stations, better velocity models and fine-tune the methodology. The locations are very close to the centroid locations, and for large events our results indicate that both at the global and the local level we can achieve a very first estimate of the directivity and finiteness if used in conjunction with a traditionally obtained hypocenter. We will coordinate with the staff at the NEIC regarding operation of the code at their site, since that would be the most appropriate location to operate the system.

The broadband monitoring system serves several useful purposes, both as backup as well as complement to the present day methods. It is also important to note that although seismically observed slow precursors to large earthquakes are very rare, they do occur, and if one were to be detected, the consequences would be very significant in terms of hazard mitigation. Since all of the instrumental infrastructure is already in place, it would only take very little cost and effort to develop the capability for detection and location of these events.

This project directly addresses a specific object in Element II: Earthquake information, monitoring and notification "In consultation with NEIC personnel, develop and implement practical methods for improving global earthquake location accuracy and inegrate with routine NEIC operations. Use creative data processing to iprove NEIC's global detection algorithms, including detection and identification of secondary phases, etc.".

Porter
Massachusetts Institute of Technology
5710001790
Dynamical change in global biogeochemical cycles accompanying early animal evolution
09/01/04-08/31/07
$52,484

Susannah Porter will be responsible for providing paleontological data and access to rock and fossil specimens from the mid-Neoproterozoic Chuar Group, western North America. Specifically, she will provide 1) rock samples for biomarker analyses; 2) ten to twenty algal microfossils from each of ~30 samples for microchemical investigations; and 3) paleontological data, including estimates of abundance and diversity along a paleoenvironmental gradient, and SEM and TEM studies of microfossil structure. Rock samples will be obtained both from collections of Chuar rocks currently housed at UCSB, and from a collecting trip conducted during Year 1. Shale samples will be processed by a palynological preparatory laboratory and in Porter's lab, and algal microfossils picked using a dissecting microscope. Paleontological data will be obtained using light microscopy, SEM, and TEM. Porter's lab has state-of-the-art light and dissecting microscopes; UCSB houses both SEM and TEM facilities.

Porter
National Aeronautics and Space Administration
NNG05GQ91G
Using skeletal microstructures to understand early animal biomineralization and phylogenetic relationships of early animals
10/01/05-09/30/07
$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
UC Los Angeles
SB060036
From Stars to Genes: An Integrated Study of the Prospects for Life in the Cosmos
10/01/05-10/31/06
$42,611

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*).

Prothero
Kelly
National Science Foundation
DUE-0231414
Collaborative Research: Moving Data Based Inquiry Learning to the Internet
01/01/03-12/31/06
$427,432

The over-arching goal of this project is to increase science literacy of general education learners who may not become scientists. The specific goal of this project is to create a well-researched oceanography course, live and online, widely disseminated, with a modern inquiry based pedagogy. The design focuses on science literacy using real earth data, collaboration between learners, and a strong connection to societal issues.

The project is based on a successful NSF CCLI pilot project that supported the creation of software and course materials that enables online auto-graded homework assignments, scientific writing activities, on demand grade calculation, and peer interaction, with powerful instructor assessment capability. It has been tested, refined, and evaluated in 2 live oceanography classes at UCSB. New capability will be created to support the fully online course with collaborative projects with strong peer to peer interactions. It will be first implemented in Spring 2003.

An instructor team has been assembled. The team consists of faculty representing 4 California community colleges, 2 California state colleges, 2 large state universities (not including UCSB), and a small private college. Yearly workshops are planned to support team collaboration and dissemination of technology and pedagogy.

Major themes are integration of technology in education and faculty development. We also expect to have an indirect impact on teacher education and diversity through the composition of the project team, some of whom have been active in teacher preparation and/or teach at campuses with a diverse student population.

Sorlien
National Science Foundation
OCE-0327273
Collaborative Research: Basin Evolution Along Continental Transforms: Nested Hi-resolution Multichannel Survey in the Marmara Sea
03/01/04-02/28/07
$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 these basin must evolve. Do continental transform basins evolve from a broad, diffuse zone towards a single-throughgoing 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 a 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.

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.

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
Department of Energy
DE-FG03-01ER15210
Mesoscale Molecular Dynamics of Geomaterials: the Class Transition, Long-Range Structure of Amorphous Silicates and Relation between Structure, Dynamics and Properties of geomaterials at elevated Temperature and Pressure
09/01/01-10/31/05
$270,000

Mesoscopic Molecular Dynamics (MMD) simulation reveals the nanoscale dynamics of collections ($\sim 10^6$-10^8) of atoms on the microsecond (10^{-6} s) timescale. MMD simulation enables one to address fundamental problems in the geo- and environmental sciences utilizing large-scale computational methods while simultaneously addressing basic scientific issues. MMD represents an ideal tool for investigation of nanostructured materials and nano-scale dynamics where clusters of particles (oft-times involving cooperative motions) are important (Smirnov, 2000; Binder, 1995). MMD informs us regarding both the structure and dynamics of materials and may be used to study phenomena as diverse as memory glass

(Kruger and Jeanloz, 1990), polyamorphism (Grimsditch, 1984; Mishima, 1994; Poole et al, 1993; Saika-Voivod et al, 2001), fracture and superplasticity in polycrystalline materials at high temperature (Holian and Ravelo, 1995; Ogawa, 1998; Bachlechner et al, 1999) and the transition between metastable (supercooled) liquid and its corresponding nonequilibrium glass, the glass transition problem (Debenedetti, 1996;Angell, 1988, 1991; Angell et al, 1997). Nano-phenomena commonly govern the macroscopic behavior of materials; if we are to understand macroscopic behavior more profoundly we must better understand processes and material structures at the atomic level. Solution of a number of practical problems in the environmental and geosciences requires better knowledge of nano-phenomena especially if one wishes to make predictions regarding structure, properties and function of materials at conditions of temperature, pressure, oxygen fugacity and activity of H_2O not amenable to experimental study such as those deep within the Earth's crust, lithosphere or deep interior.

In this proposal, we set out a program of research using the Molecular Dynamics method applied to silicate geomaterials in order to address several important geoscience problems. The workhorse tools we plan to employ are two MD codes developed at UCSB in the past decade. The first is a standard MD code that scales as N^2, where N is the number of particles used in the simulation. We have used this code extensively in the past decade (Rustad et al, 1989, 1990, 1991a,b,c, 1992, Stein and Spera, 1995, 1996, Nevins and Spera, 1998, Bryce et al, 1997, 1999, Morgan and Spera, 2001a,b). In the past year, we have developed at UCSB a new MD code based on the Fast Multipole Algorithm (FMA) of Greengard and Rokhlin (1987, 1989; Greengard and Gropp, 1990; see also Cheng et al, 1999 for an updated version). The FMA enables one to practically implement Mesoscopic Molecular Dynamics (MMD) since it provides the ability to study systems containing up to 10^8 particles over times scale of tens to hundreds of nanoseconds (e.g., see Campbell et al, 1999). We are now in the process of restructuring the code to run efficiently on parallel machines at NERSC and on a network of workstations (NoW). This level of resolution in space and time will enable a deep look into nanoscale geomaterial problems with direct application to current geoscience issues.

In the work plan set down below we explain how Mesoscopic Molecular Dynamics simulations will be used to explore the following problems: (1) The intermediate and long-range structure of M_2O-MO-Al_2O_3-SiO_2 silicate glasses and supercooled liquids. (2) The origin of dynamical heterogeneity in supercooled liquids around the glass transition temperature and its relationship to theories of viscosity such as the thermodynamic Adam-Gibbs-DiMarzio theory and the dynamical (nonequilibrium) mode-coupling theory. (3) Computing thermodynamic and transport properties of geomaterials under conditions of high pressure with special focus on the relationship between nanoscale structure and pressure in equilibrium geoliquids in the range 50-135 GPa. Properties of interest include the phonon thermal conductivity, ionic conductivity, shear viscosity, heat capacity and tracer diffusivity. These quantities for perovskitic liquids at ~5000 K are largely unknown and have important ramifications for the evolution of a putative Hadean terrestrial magma ocean, the stability and heat-transfer capabilities of possible a Ultra-Low Velocity Zone (ULVZ) of silicate melt at the core-mantle boundary as well as the convective history of the Earth's mantle. (4) Study of the nanoscale basis for superplasticity and associated grain boundary diffusion in crystalline silicates

Spera
National Science Foundation
ATM-0425059
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
Collaborative Research: Internally-Consistent Model for Trace and Major Element Evolution in Open System Magma Bodies: Merging EC-RAFC and MELTS
01/01/05-12/31/07
$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 undergraduate 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
Network Earthquake Engineering Simulation Consortium
NEES Consortium Operations 2004-2014
10/01/04-09/30/06
$836,761

Steidl
National Science Foundation
NEES Permanently Instrumented Fields Sites-UCSB Equipment Site Upgrade Proposal
CMS-0429457
10/01/04-09/30/05
$33,551

This proposal will provide NEES with two field laboratories for the study of SFSI, liquefaction, and lateral spreading. The requested funds will be used to enhance existing, well-studied, and well-characterized seismic array sites: Wildlife and Garner Valley. The enhanced NEES sites will be capable of both active and passive experiments, including an SFSI test structure with shaker and structural instrumentation at Garner Valley. As well as becoming part of NEES, both sites will interact with ANSS.

Permanently instrumented field sites for the study of soil-foundation-structure-interaction (SFSI) and soil failure address one of the identified research needs for the second round of NEES equipment/sites. There is need to further study SFSI in real structures under seismic input, but there are always complexities with real structures that can mask understanding of the SFSI phenomena. Study of soil failure is also complicated in urban or geologically-complex settings. Simple, well-characterized test sites are needed to increase understanding of the physics behind SFSI and soil failure in earthquakes.

This proposal adds to the NEES program a unique pair of permanently instrumented sites that address this research need. In particular, two simple sites in the seismically active Southern California region will be enhanced and brought into the NEES equipment portfolio, linked by next-generation wireless communications to the NEES grid. The Wildlife site will provide a test facility for active and passive measurement of soil response and soil failure under dynamic loading. The Garner Valley site will provide research opportunities for those developing tools for site characterization and for the evaluation of soil properties and how they change with time after seismic disturbance. The project will provide unique research opportunities for studying the physics of SFSI. The sites will also be an excellent test bed for new *in-situ* site characterization techniques, and new sensor technologies. The field sites will also have an impact on undergraduate and graduate teaching programs in earthquake engineering, geotechnical engineering and engineering seismology. Students will be able to participate in the active experiments through teleparticipation as well as on-site workshops. Data and research from both sites will be significant to ANSS.

Steidl
Department of Interior
06HQGR0038
Geotechnical Array Data Analysis at the ANSS Anchorage site and NEES/ANSS integration
01/01/06-12/31/06
$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 NEES/UCSB permanent field sites cyberinfrastructure.

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.

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 cyberinfrastructure. 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
Geotechnical Array Data Analysis at Borrego site and NEES/ANSS integration
03/01/06-02/28/07
$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.

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**.**

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
06HQGR0134
Geotechnical Array Data Analysis at the Hollister Earthquake Observatory and NEES/ANSS integration
03/01/06-02/28/07
$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.

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.

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
National Science Foundation
EAR-0408742
Ocean-Solid Earth Interaction: Seismic and Satellite Data
07/01/04-06/30/07
$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 shape 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. The broader impacts: This study takes advantage of seismic and satellite (ocean) data whose complimetary 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.

Tanimoto
UC-LANL
04-1206
Cause of the Continuous Oscillations of the Earth
10/01/03-09/30/05
$27,961

This is a third-year renewal request for the project " Continuous Free Oscillations and its Application to Planetary Seismology" . The main objectives of this project are twofold; (1) to understand the phenomenon of continuous oscillations of the Earth and (2) to explore its potential applicability to planetary seismology. This phenomenon is most likely an example of atmosphere-solid Earth interaction, and thus proper understanding of the continuous oscillations can only be achieved by an interdisciplinary collaboration. Collaboration between a seismologist (Tanimoto) and a geophysicist/planetary scientist who is very familiar with planetary boundary layers and atmospheric waves (ReVelle) is ideal for this purpose.

The first goal of this proposed study is to understand this phenomenon and delineate its cause. During the first and the second year, we examined seasonal variations in the amplitudes of modes and confirmed that there exist strong biannual periodicity (six months) in all good data. Stations in northern hemisphere as well as southern hemisphere exhibit similar behaviors, yielding peaks in December-January-February and June-July-August. If they were excited by atmospheric effects, they are expected to display latitudinal variations because atmospheric activity is enhanced at mid-latitudes in both summer and winter. During the second year, we intend to examine this point in more detail and clarify the spatial extent of the source of excitation.

The second goal of this study is to explore the potential existence of similar oscillations in other planets. If other planets are oscillating due to similar atmospheric effects, this process will provide an important new approach for planetary seismology. This is because, by simply installing seismic instruments on the surface of planets, we may be able to determine its normal mode frequencies. Observed eigenfrequencies will in turn provide seismic velocity structure in the planetary interior. This idea is attractive for a tectonically quiet planet such as Mars because quakes are rare for such a planet and the historical seismic approach is likely to fail. Theoretical predictions of the modal amplitudes for Mars will be computed in detail by the end of the second year, in preparation for the planned mission later during this decade (the Netlander mission in 2007).

Wyss
National Science Foundation
DEB-0317177
Collaborative Research: Andean Fossils Mammals - Phylogenetic and Geologic Implications
10/01/03-09/30/07
$150,004

The bizarre mammal fauna arising from South Americaís isolation as an island continent for most of the Cenozoic (65-0 Ma) has captivated evolutionary biologists since Darwinís 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.

Wyss
American Chemical Society
40881-AC8
Using Fossil Mammals to Unravel the Geologic History of the Central Chilean Andes
04/01/04-08/31/05
$39,500

With the revised budget and timetable, we (US graduate student, field assistant, at least one Chilean professional) will be conducting one field season at Laguna del Laja, Chile, rather than three. We will collect fossils and geochronology samples from several disjunct stratigraphic sections to determine their temporal relationship. Salary for the US graduate student is provided for three months during field work and geochronology processing, and for one summer month for the graduate student and a fraction of a month for the PI. One investigator will travel to the Field Museum in Chicago for compartive study of their South American fossil mammal collections. The 15 best geochronological samples will be processed. The results of this work will be presented at the annual meetings of the Society of Vertebrate Paleontology and the Geological Society of America, and in journal publications.

The sixteen months of awarded funding will enable us to return to collecting sites discovered previously (Trapa Trapa East, Trapa Trapa West, Cerro Los Pinos, Estero Campamento), to prospect for fossils intensively in those sites, and to seek additional primary volcanic flows for radioisotopic dating. The age diagnostic fossils and $^{40}Ar/^{39}Ar$ radioisotopic ages will be used to correlate between collecting areas, contributing, ultimately, to a reconstruction the tectonic history of the Laguna del Laja area. In summary, the shortened timeframe of our proposal curtails our field efforts to a single season and limits the amount of analysitical work to be carried out, but the goals of the project remain unchanged.

Archuleta
University of Southern California
0100810
Implementation of SCEC Research for Seismic Risk Reduction
10/01/04-09/30/06
$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 ω^{-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,

$$g(t) = g_{\text{theory}}(t) * h_{\text{site}}(t)\,.$$

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 s ynthetic records are known, the site-specific scattering functions at a station is given by

$$H_{\text{site}}(\omega) = o_s(\omega)/u_s(\omega),$$

where, $H_{\text{site}}(\omega)$ is Fourier transform of $h_{\text{site}}(t)$; $o_s(\omega)$ and $u_s(\omega)$ 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. By statistically analyzing this set of ground motion predictions based on our kinematic model, we can obtain the mean values and variances of ground motion parameters such as peak values, spectral values and other measures of ground motion (Kramer, 1996). Because of the small-scale complexity of source, path and site, one cannot avoid the uncertainty in any prediction of ground motions from future earthquakes. However we can estimate this uncertainty.

We will extend the methods developed in Years 1 and 2 to other scenario earthquakes in the Los Angeles basin. We will also generate synthetics to be compared with the extensive data set from the 2004 Parkfield earthquake.

Burbank/Archuleta
University of Southern California
075639-A
SCEC2 Participation: Radiated Seismic Energy from Models of Dynamic Faulting
0/01/02-01/31/07
$67,000

We propose to compute the seismic radiated energy for the 1994 Northridge earthquake. First, we will determine the initial stresses from the slip distribution using the method of *Bouchon* (1997). The initial stresses will be based on the slip distribution derived by *Liu and Archuleta* (2002). Because of a reduced budget we may not be able to consider the slip distribution derived by *Wald et al*., (1996). 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 (*Favreau and Archuleta*, 2003). This research will be carried out by Shuo Ma, a graduate student at UCSB under supervision by the principal investigator.

Burbank/Archuleta
University of Southern California
075639-B
SCEC2 Particpation: SCEC Strong Motion Database (SMDB) Project B
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.

Burbank/Archuleta
University of Southern California
075639-AC
A Collaborative Project: 3D Rupture Dynamics, Validation of the Numerical Simulation Method
02/01/02-01/31/07
$41,000

Rupture dynamics modelers who consider the physics of earthquakes use a range of 3D computational methods to simulate earthquake behavior. These methods include finitedifference, finite-element, spectral element, and boundary integral techniques. Although there have been a few small comparisons of two computer codes for a limited range of test cases, it was not until the kick-off SCEC code-validation exercise in November 2003, that anyone had ever undertaken 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. However, if the computer programs work differently, then the conclusions drawn from the simulations may well not agree, rendering the findings unusable by the broader community.

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 should 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 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, SHA, and Fault Systems Focus Groups. For the latter, a number of PI's are now linking 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). In addition to intra-SCEC impact, this exercise now has an international following. This collaborative SCEC effort is the lead-player, with scientists from at least 5 other countries (Japan, Switzerland, Italy, Germany, Slovakia, etc.) closely following our progress and using our results for their own code-testing.

Burbank/Archuleta
University of Southern California
075639-X
Quantifying the Variability in Linear Site Response
02/01/02-01/31/07
$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, $\sim f^{0.05}$. 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.

Burbank/Archuleta
University of Southern California
075639-AC
SCEC2 Participation: Inversion of Seismic and Geodetic Data from the 2004 Parkfield Earthquake
02/01/02-01/31/07
$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.

Burbank/Lavallee
University of Southern California
075639-O
Study and Modeling of Complexities of the Slip Spatial Distribution for Large Earthquakes
02/01/02-01/31/07
$32,000

Earthquakes are complex phenomena. The origin of complexity in earthquake has been attributed to nonlinear effects in the friction law on the fault (Carlson and Langer, 1989). Instead, Rice (1993) suggested geometric disorder of fault zones and fractal-like surface roughness of faults as the causal candidates responsible for seismic complexity. Note that even relatively simple models of faulting predict high spatial variability in stress drop over the fault (Madariaga and Cochard, 1994). Although the origin of complexities in earthquakes is still the object of debate, finite-fault source inversion of well recorded earthquakes reveal the complexity of both the slip and drop stress spatial distribution over the fault surface. The first evidence of the complex behavior was presented in papers by Das and Aki (1977), Aki (1979) and Day (1982). Hartzell and Heaton (1986) and Beroza and Spudich (1988) computed the rupture history of the 1984 Morgan Hill earthquake and showed that the spatial distribution of slip over the fault surface was very heterogeneous where regions of high slip alternate with regions where little slip occurred. Using near-field strong motion data to compile the stress generated during a fault rupture for the Imperial Valley earthquake of 1979; the Morgan Hill earthquake of 1984; the Loma Prieta earthquake of 1989; and the Nothridge earthquake of 1994; Bouchon (1997) concludes that a “consistent feature of the four earthquake studied is the strong heterogeneity of the stress drop distribution over the fault.” The same conclusions were reported for the studies of Landers earthquake of 1992 (Bouchon *et al.*, 1998a) and for the Hyogo-ken Nanbu earthquake of 1994 (Bouchon *et al.*, 1998b).

Through the disorder that characterizes an earthquake’s spatial distribution of stress/slip, many authors have identified the importance of spatial pattern. For example, it has been argued that the presence of patches with high stress values is essential for rupture to expand. Assuming different planar fault geometry, Andrews (1976) and Day (1982) have computed the critical lengths characterizing the size of the minimum patches. Introducing the effect of lubrification in fault mechanics, Brodsky and Kanamori (2001) note that many discontinuous lubricated regions are required at the surface of the fault in order to observe slipping. In numerical modeling the 1994 Northridge, California, earthquake, Nielsen and Olsen (1999) not only concur that high stress patches on the fault are needed for rupture to process, but they also introduce the idea that connectivity between the patches is also essential for the progression of the rupture front. This suggests that earthquake rupture propagation can be understood as a critical phenomena such as that found for phase transitions, percolation theory, etc.

The goals of this project are two fold. First (short term), to study and to characterize statistically the heterogeneous spatial distribution of stress along the fault surface. Second (short to long term), to study the causal relationship between fault rupture and the level of connectivity between patches with high stress values. For this purpose we have developed a stochastic fault model that reproduces the statistical properties and the spatial variability of the static stress drop distribution of the 1992 Landers earthquake. We also investigated how the pattern and patches of high stress are spatially organized over the fault surface for the static stress drop distribution of the 1992 Landers earthquake. We were able to estimate a critical threshold value of the stress drop for which a "cluster" connects one side of the fault to the other. Analysis of the connectivity function and the correlation length suggest that earthquake prestress distribution is a critical phenomena (Grimmett, 1991; and Stauffer and Aharony, 1991). The same analysis performed to the Landers earthquake should be applied to other earthquakes to corroborate our finding and interpretation of the effect of stress connectivity as a critical phenomena. This is a question closely related to the issue of “dynamic triggering” identified as a short term priority of SCEC2. A good candidate for this analysis is the Imperial Valley earthquake of 1979. The long term objective is to understand the interdependence between connectivity and the propagation of the rupture front. For this purpose the stochastic fault model will be used to generate different realizations of the prestress spatial distribution with different degrees of connectivity. For each realization an earthquake scenario will be computed using a dynamic rupture model. A potential outcome of this project will be the determination of a criterion that discriminates spatial distribution of heterogeneities that allow the rupture front to progress from those distributions that stop rupture propagation—basically a criterion that physically represents the difference between large and small magnitude events.

Burbank/Lavallee
University of Southern California
075639-AC
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?

Burbank/Liu/Archuleta
University of Southern California
075639-C
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.

Burbank/Liu/Archuleta
University of Southern California
075639-P
SCEC2 Participation: 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.

Burbank/Liu/Archuleta
University of Southern California
075639-AC
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 develope 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.

Burbank/Niemi/Oskin
University of Southern California
075639-Z
SCEC2 Participation: 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 welldocumented 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.

Burbank/Niemi
University of Southern California
075639-AA
SCEC2 Participation: 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. 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), 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.

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 where this method can yield important new results on the distribution of seismic hazard from contractional faultrelated fold growth:

> (1) The Puente and Coyote Hills, 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, 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. Yeats (1977, 1987), Yeats et al., (1994), Yeats and Huftile (1995), and Huftile and Yeats (1996) have quantified longterm 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.

Burbank/Olsen
University of Southern California
075639-E
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.

Burbank/Olsen
University of Southern California
075639-F
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.

Burbank/Olsen
University of Southern California
075639-G
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.

Burbank/Olsen
University of Southern California
075639-H
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.

Burbank/Olsen
University of Southern California
075639-Q
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.

Burbank/Olsen
University of Southern California
075639-R
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.

Burbank/Olsen
University of Southern California
075639-R
SCEC 2 Participation: How Can We Improve Ground Motion Estimates by Lessons
02/01/02-01/31/07
$15,000

Burbank/Oskin
University of Southern California
075639-I
SCEC2 Participation: Toward a Structural Representation of the Plieto Thrust System and the Architecture of Transpressive Fault Systems
02/01/02-01/31/07
$20,000

Geologic studies in the previous 10 years under the guidance of SCEC have significantly advanced our understanding of the structure and kinematics of the Pacific- North America plate boundary fault system in southern California (Working Group on California Earthquake Probabilities, 1995; SCEC group C., 2001). Where significant discrepancies remain between geologic and geodetic strain estimates, these areas are often within the transpressive fault systems of the central and western Transverse Ranges where complex interactions occur between strike-slip and reverse fault systems. This region has been the locus of considerable debate over the geometry of reverse faults (e.g., 'thin-skinned' or 'thick-skinned') and the interaction of strike-slip and reverse faults (e.g., Shaw and Suppe, 1996; Sneider et al., 1996). These issues are central to resolving outstanding strain-rate discrepancies in southern California, such as compression across the Los Angeles basin (Walls et al., 1998) and strike-slip through San Gorgonio Pass (Spotilla and Sieh, 2000). Resolution of these problems will have broad implications for the distribution of seismic hazard in southern California and for discerning the short-term and long-term behavior of fault networks.

The Plieto thrust system, comprising the Plieto, Wheeler, and Tejon/White Wolf faults, presents an ideal natural laboratory to test competing models for the architecture of transpressive fault systems. The structural setting of the San Emigdio Mountains and the ~100 km-long Plieto thrust system form an exemplary transpressive tectonic system, nestled within the northernmost reach of the compressive 'big bend' of the San Andreas fault at the intersection of the highest-slip-rate right-lateral and left-lateral faults in southern California The Plieto thrust system builds the basement-cored San Emigdio Mountains northward, over the southern margin of the San Joaquin basin (Davis, 1983; Goodman, 1989) with uplift rates of at least 2-3 mm/yr (Keller et al., 2000) and historic seismicity (1952 Arvin-Tehachapi, MW 7.3, Stein and Thatcher, 1981). Much of the growth of the San Emigdio Mountians involves Pliocene and Quaternary syntectonic sedimentary rocks that preserve a detailed record of fault-related folding with outstanding geomorphic expression (Keller et al., 1998, 2000). Both thin-skinned (Davis, 1983; Davis et al., 1996) and thick-skinned (Goodman and Malin, 1992) thrust geometries have been proposed for the Plieto thrust system. Each of these fault solutions must interact with the nearby San Andreas and Garlock faults within the crust, perhaps even within the seismogenic upper crust (Davis et al., 1996).

The goal of the study proposed here is to build a structural representation of the Plieto thrust system with new constraints from tectonic geomorphology and growth strata (e.g. Suppe et al, 1997; Thompson, 2000). These new data sets will be used to differentiate active and inactive fold structures and thus to infer the underlying fault geometry. The results of this study will answer several fundamental questions regarding the architecture of the Plieto thrust system and lend important insight into the nature of transpressive fault systems:

- Is the Plieto thrust system dominantly thin-skinned, where most of the folds are built above ramps within one or more detachment levels? Or, is the Plieto thrust system thick-skinned, with multiple, simultaneously active fault-cored folds (e.g., Goodman and Malin, 1992)?
- How does the Plieto thrust system interact with the adjacent San Andreas and Garlock faults? Are there along strike gradients in deformation related to the evolution of the unstable San Andreas-Garlock triple junction?
- What is the rate of convergence across the Plieto Thrust system? What proportion of shortening is accommodated by folding? How may shortening in the Plieto thrust system affect regional seismic hazard estimates and the earthquake cycle on the adjacent San Andreas and Garlock faults?
- Are there potential sites for investigation of coseismic rupture and folding on the Plieto thrust system?
- How does the geometry and kinematic evolution of the Plieto thrust system compare to other large-scale transpressive structures in southern California, such as the Cucamonga-San Jacinto-San Andreas system, the San Gorgonio pass fault, and the northern Los Angeles basin?

We anticipate that study of the Plieto thrust system will add an important new data set to both regional and local seismic hazard assessments, as well as leading to new ideas regarding the architecture of transpressive fault systems in southern California. This study will have a direct benefit to understanding seismic hazard in Kern county, one of the fastest growing areas of California. Moreover, by testing specific models of thrust tectonics withiin the Transverse Ranges, this study will develop regionally important concepts for understanding the transpressive plate boundary system through southern California.

Burbank/Oskin
University of Southern California
075639-J
SCEC2 Participation: What is the Relative Magnitude of Transient Loading of the Blackwater Fault?
02/01/02-01/31/07
$30,000

Does transient loading of faults occur, and can this process trigger earthquakes? Past observations indicate systematic fault behavior consistent with transient stress triggering. For example, sequential rupture of the North Anatolian fault in a series of six earthquakes over magnitude 7.0 from 1939-1967 suggests that each rupture loaded an adjacent fault segment (Ambraseys, 1970; Stein et al., 1997). Postseismic relaxation following the magnitude 7.3 1992 Landers earthquake may have transiently loaded the adjacent nucleation point of the magnitude 7.1 1999 Hector Mine event (Pollitz and Sacks, in press). Paleoseismic studies of the Eastern California Shear Zone also indicate earlier clusters of earthquakes here (Rockwell et al., 2000), supporting the concept of stress triggering as an important component of near-term seismic hazard.

Recent geodetic observations of the Eastern California Shear Zone indicate that transient loading may be occurring presently on and northwest of the Blackwater Fault (Peltzer et al., 2001). The Blackwater fault forms the principal, northwest-striking, active right-lateral structure of the Eastern California Shear Zone north of the 1992 Landers rupture and south of the Garlock Fault (Fig. 1; Dokka, 1983). Peltzer et al. (2001) suggest loading of the Blackwater fault at an effective strain rate of 7±3 mm/yr, which is ~3 times greater than the long-term geologic rate of slip for the Blackwater Fault estimated by Dokka and Travis (1990a). Transient loading is also supported by the lack of strain measured for the northeast-striking, active left-lateral Garlock Fault, which crosses the trend of the Blackwater fault at its northwestern end. Because both the Garlock and Blackwater faults show geologic evidence for recent activity (McGill and Sieh, 1993; Dokka, 1983), Peltzer et al. (2001) suggest that their observations may be part of an oscillatory strain pattern between crossing, conjugate fault systems. Loading derived from coseismic slip and viscoelastic relaxation following the 1872 Owens Valley, 1992 Landers, and 1999 Hector Mine earthquakes is suggested as a possible cause for the present state of active strain across the Blackwater fault trend.

Although the preferential loading of the Blackwater fault over the Garlock fault is clear from the data presented by Peltzer et al. (2001), the long-term rate of slip on the Blackwater fault is very poorly constrained at present. The 1-2mm/yr rate calculated by Dokka and Travis (1990a) and cited by Peltzer et al. (2001) is estimated from a pair of 13-to-18-Ma markers offset ~10 km and combined with a 6-to-10-Ma time of inception of faulting. However, these timing constraints are only regionally applicable to the entire Eastern California Shear Zone (Dokka and Travis, 1990b). Both Dokka and Travis (1990a,b) and studies of the Basin and Range north of the Garlock fault (e.g. Wernicke et al., 1988) recognize a significant westward migration of the locus of dextral shear since 10 Ma. Initiation of faulting in the south-central Mojave area may have begun as recently as 1 Ma (Dokka and Travis, 1990b) and 7 km of slip here may have been predominantly carried to the northwest by the Blackwater fault (Fig. 1). These observations suggest that the slip rate of the Blackwater fault could be as high as 7 mm/yr, and thus comparable to the magnitude of transient loading suggested by Peltzer et al. (2001). This leads to the primary question to be addressed by the proposed study:

- What is the Quaternary displacement rate of the Blackwater fault, and how does this compare to the proposed magnitude of transient loading?

The resolution of this question will have important scientific implications for the future of near-term seismic hazard estimates. If transient loading is verified to be several times the Quaternary slip rate, then combined geodetic and neotectonic observations may be used to highlight faults of increased near-term hazard. Alternatively, if the Late Quaternary slip rate on the Blackwater fault is similar to the observed geodetic rate of loading, then Peltzer et al. (2001) may have measured part of the longer-term loading process, unrelated to near-term seismic hazard.

In addition to testing the provocative hypothesis of Peltzer et al. (2001), measurement of a late Quaternary slip rate for the Blackwater fault will address several additional scientific problems related to seismic hazard in southern California:

- What is the role of the Blackwater fault in accommodation of Pacific-North America plate motion? Does the Blackwater fault carry a large proportion of strain in the Eastern California Shear Zone?
- Is the Blackwater fault a 'category 1' structure, with a slip rate in excess of 4 mm/yr, and thus should this fault be considered individually in future seismic hazard and kinematic models?
- How does the intersection of the Blackwater and the Garlock fault work? Do both of these faults slip at comparable rates of ~7 mm/yr? If so, then how quickly has the Blackwater-Garlock junction evolved, and how has Garlock fault maintained its trace? Does slip on the Blackwater fault diminish northwestward and transfer onto other structures in the northeastern Mojave desert?

Although the Blackwater fault lies far from major population centers of southern California, the outstanding scientific questions raised by recent geodetic measurements (Peltzer et al., 2001) indicate that this fault deserves a closer look. When compounded by the lessons on earthquake clustering learned from elsewhere in the Eastern California Shear Zone (e.g. Rockwell et al., 2000; Pollitz and Sacks, in press) and nearby historic, large-magnitude earthquakes both to the north and south (Beanland and Clark, 1994; Sieh et al., 1993), the Blackwater fault emerges as an area of both special concern and great potential for learning about future earthquake hazards.

Burbank/Oskin
University of Southern California
075639-S
SCEC2 Participation: Fault Versus Off-Fault Deformation of the E. CA Shear Zone
02/01/02-01/31/07
$20,000

Satellite geodesy is a powerful monitor of strain energy build-up. However, how much of this energy is released by earthquakes on major faults? Is a significant proportion of crustal strain absorbed by smaller fault offsets and distributed off-fault deformation? These questions address fundamental problems in understanding earthquake processes and seismic hazard:

- How does geodesy relate to long-term plate boundary deformation – e.g., should geologic slip rates on major faults and geodetic data agree?
- Does distributed off-fault deformation diminish total seismic hazard by dissipating strain energy?
- Is significant strain energy released by rare events on a distributed, cryptic system of low-slip-rate faults?

Existing data from southern California support contrasting answers to the fault versus off-fault deformation problem. Fault slip rates and geodetic strain accumulation rate appear to match across the Peninsular Ranges of southern California (Lisowski t al., 1991). Across the Eastern California Shear Zone (ECSZ), however, geodetically measured strain accumulation rates from 10 to 14 mm/yr may exceed the summed slip rate of known strike-slip faults by perhaps a factor of two or greater (Rockwell et al., 2000; Miller et al., 2001; McClusky et al., 2001). Evidence from the ECSZ supports temporal clustering of strain release (Rockwell et al., 2000) and the strong possibility of non-steady strain accumulation (Peltzer et al., 2001; Oskin, 2002) which may help to explain at least some of the discrepancy between geologic and geodetic data.

An alternative hypothesis to explain mismatch between geodetic and geologic data is that significant deformation is accommodated between faults by distributed small fault offsets and bulk shear strain (Thatcher, 1995). Empirical evidence from the complex rupture geometry of the 1992 Landers and 1999 Hector Mine earthquakes supports that earthquakes in the ECSZ may rupture through multiple individual faults and include previously unrecognized or unconnected fault segments (Sieh et al., 1993; Trieman et al., 2002). Highly uneven slip and distributed coseismic warping measured from the 1992 and 1999 fault breaks also suggests that significant slip may be missed by focusing geologic observations just on major fault traces. If distributed processes account for the remaining geodetic shear strain not accommodated by faults of the ECSZ, then small fault offsets and distributed shear strain should accommodate for 50% or more of total displacement. Under ideal geologic conditions, this substantial proportion of offfault strain should produce a measurable signal of long-term permanent deformation.

I propose to investigate the problem of fault versus off-fault deformation from a unique geologic setting within the ECSZ where both fault and off-fault deformation is well-preserved and measurable. The Black Mountains basalt field, located within the ECSZ northwest of Barstow, California (Fig. 1) was emplaced across two adjacent major strike-slip faults of the ECSZ. Previous SCEC-funded research along the Blackwater fault established a well-dated basalt flow stratigraphy for part of the Black Mountains basalt field (Fig. 2; Oskin, 2002). The research proposed here will extend this mapping across the adjacent Gravel Hills fault and compile an inventory of small fault offsets and distributed vertical axis rotation both within and in-between both fault zones. The result of this study will be a one-of-a-kind data set combining major-fault slip, distributed minor faulting, and paleomagnetic measurements of distributed rotational strain. Interpretation of this data set will bring new understanding to the distribution of strain accumulation within the ECSZ with important implications for geologic and geodetic observations of plate boundary zones and resultant seismic hazards.

Burbank/Oskin/Niemi
University of Southern California
075639-T
SCEC2 Participation: 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.

Burbank/Sorlien
University of Southern California
075639-K
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.

Burbank/Sorlien
University of Southern California
075639-U
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.

Burbank/Sorlien
University of Southern California
075639-Y
SCEC2 Participation: 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 (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, 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 (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.
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 (Seeber and Sorlien, 2000).

Burbank/Sorlien
University of Southern California
075639-AC
SCEC2 Participation: 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 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. 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. 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, 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.

Burbank/Steidl
University of Southern California
075639-L
SCEC Borehole Instrumentation Program
02/01/02-01/31/07
$90,000

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.

Burbank/Steidl
University of Southern California
075639-M
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.

Burbank/Steidl
University of Southern California
075639-V
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 tranfer matrix that incorporates the ability to accurately include frequency dependence of attenuation. The synthetics will be generated using the borehold 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.

Burbank/Tanimoto
University of Southern California
075639-N
SCEC2 Participation: Large-Scale 3D Crust and Upper Mantle Structure in Southern California from TriNet Broadband Data Set
02/01/02-01/31/07
$20,000

Taking advantage of a vast amount of broadband seismic data from TriNet, we propose to construct a model of 3D large-scale structure in Southern California. Specific data to be analysed are teleseismic surface waves and body waves recorded by TriNet. The resulting structure will be of a lower resolution than the one developed by the Community Velocity Model but has two attractive features:

- S-wave velocity structure in the crust and mantle down to a depth about 100 km can be constrained. The model will constrain large-scale features of 3D structure in the crust and mantle and thus *may serve as a good starting model for the inversion of more detailed 3D structure*.
- The model provides a well-constrained overview of long-wavelength features in the entire Southern California. *It will help us understand the overall tectonic features.* Our preliminary maps contain some surprising features that may lead to new understanding of large-scale tectonics in this region.

We have collected phase velocity data from TriNet for about 3000-4000 paths for Rayleigh and Love wave data and are in the process of measuring body wave differential travel times for about 70 events we have collected so far. During the proposed period of this study, we will develop a 3D S-wave velocity model for Southern California which will satisfy both surface waves and differential body wave travel times. We will also examine existing P-wave velocity models (e.g., Kohler et al., 2001) by measuring P-wave differential travel times in TriNet data.

Burbank/Tanimoto
University of Southern California
075639-W
SCEC2 Participation: Testing & Improving the SCEC Community Velocity Model 3.0
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.

Burbank/Tanimoto
University of Southern California
075639-AB
Improving S-Wave Velocity in the SCEC Community Velocity Model through Teleseismic Broadband Data
02/01/02-01/31/07
$50,000

Taking advantage of a vast amount of broadband seismic data from TriNet, we propose to construct a model of 3D large-scale structure in Southern California. Specific data to be analyzed are teleseismic surface waves and body waves recorded by TriNet. The resulting structure will be of a lower resolution than the one developed by the Community Velocity Model but has two attractive features:

- S-wave velocity structure in the crust and mantle down to a depth about 100 km can be constrained. The model will constrain large-scale features of 3D structure in the crust and mantle and thus *may serve as a good starting model for the inversion of more detailed 3D structure*.

- The model provides a well-constrained overview of long-wavelength features in the entire Southern California. It will help us understand the overall tectonic features. Our preliminary maps contain some surprising features that may lead to new understanding of large-scale tectonics in this region.

We have collected phase velocity data from TriNet for about 3000-4000 paths for Rayleigh and Love wave data and are in the process of measuring body wave differential travel times for about 70 events we have collected so far. During the proposed period of this study, we will develop a 3D S-wave velocity model for Southern California which will satisfy both surface waves and differential body wave travel times. We will also examine existing P-wave velocity models (e.g., *Kohler et al*., 2001) by measuring P-wave differential travel times in TriNet data.