Highlights of Research Activities for 1993/1994

1. Crustal Structure and Tectonics

Personnel: A. Blythe, C. Busby, S. Cisowski, J. Crowell, G. Ely, M. Kamerling, E. Keller, J. Lees, **B. Luyendyk***, C. Nicholson, B. Patrick, N. Pinter, C. Smith, C. Sorlien, A. Sylvester, T. Tanimoto, (* Agenda coordinator)

Fission track studies in Alaska and Spitsbergen (Ann E. Blythe)

Blythe is currently completing a study that examined the cooling history of the south-central Brooks Range, Alaska. The data indicates that northern Alaska has been affected by a complex pattern of Tertiary cooling and uplift, long after the major deformation was thought to have ended in northern Alaska. In the Arrigetch Peaks region of the south-central Brooks Range, zircon fission track ages (representing cooling through ~210°C) are 40 Ma and apatite fission track ages (representing cooling from ~110 to 60°C) are 33 Ma. Much older zircon and apatite fission track ages (80 and 60 Ma, respectively) are obtained from regions to the north and south of the Arrigetch Peaks. The data collected indicates that the Arrigetch Peaks have undergone a substantial amount of uplift and erosion during Tertiary time. This discovery is of importance because it suggests that significant structural and/or thermal events were occurring during Tertiary time in northern Alaska, a region where the major tectonic activity was thought to have been completed by middle Cretaceous time. One can expect a more detailed description of these findings in a manuscript to be published in the near future by both Anne Blythe and Brian Patrick.

In addition Anne Blythe has also recently completed a major project on the cooling history of Spitsbergen with Karen Kleinspehn at the University of Minnesota. Their data (33 apatite and 9 zircon fission ages) indicates that substantial uplift and cooling occurred throughout Spitsbergen at ~38 million years ago, the time at which Spitsbergen rifted away from Greenland.

Paleomagnetic investigation of ODP Leg 155 Samples (Stan Cisowski)

Cisowski participated in Leg 155 of the Ocean Drilling Program, and is currently engaged in paleomagnetic analysis of the ocean sediments from that cruise. High resolution records of paleomagnetic secular variation and geomagnetic excursions were obtained from shipboard measurements. Future research will further refine these records with discrete sample measurements. Also an attempt will be made to seek a correlation between magnetic events and global climate change over the past ~100,000 years. This correlation will involve a synthesis of Cisowski's paleomagnetic data with oxygen and carbon isotope data on the same samples, compiled by other researchers who participated in the same cruise. The initial results from this effort indicate the potential of generating a much more detailed geochronology of the Late Pleistocene than was previously available. This follows from the exceptionally high sediment accumulation rates within the Amazon fan, which resulted in a paleomagnetic and geochemical signal of exceptional detail.

Undergraduate Research at UCSB: Focus on the Environment (Ed Keller)

The Santa Cruz Island fault (SCIF) is the principal geomorphic feature of Santa Cruz Island, largest of the California Channel Islands and southern margin system of faults that separates the east-west trending Western Transverse Ranges from the northwest-southeast trending features of the California borderland and the Los Angeles basin to the south. This system is associated with left-lateral and oblique-thrusting earthquakes and deformation.

The principal objective of this research was to excavate a trench on the SCIF. A suitable trench site was located at the western end of the Santa Cruz Island central valley, at Christi Beach. The Christi Beach trench exposure was extensively faulted and was rich in charcoal and shell fragments. Excavations revealed a sequence of fluvial and debris-flow deposits that appear to date to the last two cycles of rising eustatic sea level: approximately 35-28,000 years ago and 18-5,000 years ago, as well as intensely deformed fragments of underlying rock units. The geometry of faulting revealed in the Christi Beach trench is most consistent with left-lateral oblique motion, including a component of thrust motion. Available age control suggests that several rupture events have occurred at the site since approximately 33,400+/-420 years ago and that the last earthquake to rupture the deposits in the Christi Beach trench occurred between 33,400+/-420 and 5,440+/-80 years ago. No evidence of faulting was found higher in the sequence. Additional age control will be necessary to further refine the age of the last slip event on the SCIF.

Geomorphology Undergraduate Research Mentorship Program (Edward Keller and Nicholas Pinter)

The Geomorphology Research Mentorship Program was designed as a fusion of cutting-edge research and undergraduate education. In this first year, four undergraduate students from U.C. Santa Barbara worked one-on-one with five graduate and postdoctoral scientists on Santa Cruz Island, about twenty miles off the Santa Barbara coast, on an on-going project to investigate the history of active faulting and earthquake hazard on the island. After one week of training on the mainland, each student was paired with one mentor, and those teams worked for four weeks on Santa Cruz Island on individual research projects. All of those research projects were elements of one main scientific problem. Although the research teams helped each other as needed, the heart of the effort was the student-mentor relationship, in which each student learned specific technical skills (such as surveying, geologic mapping, and analysis of soils) as well as general strategies for solving geological problems in the field. Field research was augmented by assigned readings, lessons in data analysis, writing assignments, student presentations, and group discussions of the various research problems. The great success of this program in 1994 has led to the expansion of the program and ultimately to a proposal for an NSF Research Experiences for Undergraduates (REU) Site.

Geometry and kinematics of Late Cenozoic deformation in the Northeast Mojave Desert (Bruce Luyendyk and Stan Cisowski)

This project is collaborative between Stan Cisowski and Bruce Luyendyk of ICS/UCSB and Elizabeth Schermer of Western Washington State University. The project goal is to understand the Late Cenozoic tectonics in the northeast Mojave Desert. Specifically, the region is characterized by east-west trending elongate fault blocks rather than the NNW-ESE trending dextral faults typical of the Mojave. The question is what is responsible for this structural contrast; for example, is it due to vertical axis clockwise tectonic rotations? This area is within the Eastern California Shear zone and represents a connection between the strike slip faults in the eastern Mojave and the Death Valley fault zone to the north. Luyendyk and Cisowski were responsible for study of the paleomagnetism of Neogene volcanic rocks from the region of Fort Irwin in the northeast Mojave. Schermer and her students conducted field mapping and geochronology studies.

Collectively they obtained samples from 51 sites in basalts and dacites in the region. $^{40}Ar/^{39}Ar$ dating shows that these rocks are early and middle Miocene in age with a minor occurrence of Pliocene basalts. Both east-northeast (clockwise) deflected and northwards declinations are found. Rock magnetic experiments suggest that some of the northwards directions are remagnetized directions and some are primary. The clockwise directions are deflected about 50° to 60° and are believed primary. As an independent check, the Jurassic Independence Dike Swarm within the elongate blocks is differentially rotated clockwise relative to the swarm north of the Garlock fault, an amount similar to the declination vectors. This suggests that the ENE declinations are primary and caused by tectonic rotation. Field mapping indicates that the E-W faults are sinistral with only a few kilometers of offset. They do not follow pre existing lines of structural weakness. If interpreted as the declination data as a clockwise rotation of elongate fault blocks, much more offset is predicted than is observed. However, the data may also be interpreted as small block rotations, or a combination of elongate block rotation and additional rotation of small blocks at the edges of larger blocks. Other geophysical data are needed to help search for buried block boundaries. Without additional information it can only be determined that clockwise rotations have accompanied sinistral faulting in this area, but not the dimensions of the rotating blocks.

Geological of geophysical studies in the Ford Ranges of Marie Byrd Land, West Antarctica (Bruce Luyendyk, Christine Smith and Stan Cisowski)

Research in West Antarctica is aimed at the tectonics of Gondwana and later rifting in this sector. It has included three expeditions the last of which was on the German GANOVEX VII in 1992-93. During this past year Smith conducted further geochemical analyses on Cretaceous migmatites and completed her dissertation research. Luyendyk and Cisowski completed their paleomagnetic study of northern Ford Ranges rocks and submitted a paper to *Tectonics*. By combining their data with $^{40}Ar/^{39}Ar$ cooling ages it was determined that block faulting in the Ford Ranges occurred between 105 and 103 Ma which dates the beginning of extension here. It was also determined that a mid-Cretaceous paleomagnetic pole exists which is concordant with other results from Marie Byrd Land. This means that western Marie Byrd Land has not been tectonically transported relative to the other West Antarctic terranes since mid-Cretaceous times.

Luyendyk developed a new hypothesis for the mechanism which resulted in Gondwana rifting. This is the subducted slab capture model developed for the California margin. Luyendyk proposed that the continental margin of east Gondwana was rifted off because the underlying subducted slab was captured by the northward moving Pacific plate. Friction lock between the captured slab and the overlying margin caused the margin to join in this northward transport. A paper has been submitted to *Geology*.

Luyendyk has also completed gravity and bathymetry maps for western Marie Byrd Land. Gravity data were taken by J. Beitzel in 1966-67 and by Luyendyk in 1992-93. Echo sounding data were taken on the GANOVEX VII expedition and supplemented by soundings from *Deep Freeze '62* and *'83* . The gravity map covers the Ford Ranges and most of Edward VII Peninsula. Free Air gravity outlines troughs of likely glacial origin under the shelf ice; it also indicates that the margin is under compensated consistent with recent ice sheet unloading. Bouguer gravity shows a 100 mGal high offshore from the southern Ford Ranges and a 60 mGal high over the metamorphic culmination in the Fosdick Mountains. The bathymetry mapping reveals two glacial troughs or basins offshore from the southern Ford Ranges.

Microplate Capture, Large-scale Rotations, and Initiation of the San Andreas Transform: Test of a New Tectonic Model (Craig Nicholson, Marc Kamerling)

Nicholson and Kamerling have developed a new tectonic model for the evolution of the Pacific-Northwest. The model is based on a wide variety of geological and geophysical evidence both onshore and offshore of California, and is the first model to adequately explain certain unusual features of the California margin, such as the rotated western Transverse Ranges (WTR) province. The WTR have tectonically rotated substantially since early-Miocene time and continue to rotate today. This rotation has been closely linked to the evolving Pacific-North American transform boundary and, more recently, to large-scale extension and rifting of the inner California Continental Borderland. However, it has never been explained as to exactly why the WTR should accommodate such plate boundary deformation by tectonic rotation, or exactly why they should have developed when and where they did. Based on research data, Nicholson and Kamerling propose that the rotation of the WTR block is the direct result of capture of the partially subducted Monterey microplate by the Pacific plate previously documented to have occurred at about anomaly 6 time (~20 Ma). As Pacific-Monterey spreading slowed and eventually ceased, the slip vector along the gently-dipping subduction interface beneath the California margin changed from slightly oblique subduction to transtensional dextral transform motion. This implies that the San Andreas transform initiated as a system of low-angle faults, which locally subjected the overriding continental margin to distributed basal shear and crustal extension. This model helps explain; the timing of initial WTR rotation and associated basin formation, the sudden appearance of widely-distributed transform motion well inland of the margin in early-Miocene time, why the WTR uniquely rotated as a large coherent crustal block, and some of the fundamental structural characteristics of central and southern California. The model also provides; major constraints on the amount of Pacific-North America strike-slip motion, the relative position through time of offshore oceanic plates with respect to onshore geology, and a general explanation for what may happen as a spreading ridge approaches a trench and the subduction zone evolves into a transform system.

Analysis of the 1992 M6.1 Joshua Tree Earthquake sequence and its relation to the San Andreas Fault system, California (Craig Nicholson and Jonathan Lees)

This grant allowed Nicholson and Lees to develop a new computer program to interactively manipulate a broad range of geophysical and geological data for exploratory analysis and presentation. The program is similar to GIS systems that allow ascii data-bases stored in memory to be accessed through a user-friendly graphical interface, but differs in that it allows users to interact with data in a third dimension. Data can be viewed in either map or cross section, and at any strike or dip. The program is called Xmap8. Xmap8 was primarily designed to handle large sets of earthquake-related data. Color-coded geological and geophysical maps (or cross sections) can be overlain with earthquake hypo centers, focal mechanisms and station arrays. Special attention has been put into dynamic plotting of earthquakes as time sequences, connecting related events derived from different velocity models or phase data, and plotting earthquakes with a variety of options related to hypocentral parameters. Several different views of earthquake focal mechanisms are available including traditional beach-ball type plots, P- and T-axes, or single nodal planes with slip vectors, color-coded as a function of rake. Users are allowed to select individual nodal planes from suites of focal mechanisms, that align with seismicity trends in space and time, as a means of identifying structural details of subsurface fault geometry. A contouring package is included for plotting 2-D surface or subsurface field data in map view, or for projecting contour slices in cross section. 3-D projection of deviated wells, dipmeter logs, and well stratigraphy color-coded by lithology, in both map and cross section, makes visual correlation of many diverse data sets intuitive. Hard-copy output of graphic displays is all done in PostScript. Nicholson and Lees have used the program to study a number of complex crustal problems including; fluid injection and seismicity at the Coso Geothermal Field, organizing focal mechanisms from the 1992 Joshua Tree sequence, delineation of the magma chamber and seismicity at Mt. St. Helens, and relating structural subsurface features in the Santa Barbara Channel.

3-D analysis of Seismicity, Focal Mechanisms and Stress using the 1992 Joshua Tree Earthquake Sequence, Southern California (Craig Nicholson, Geoff Ely, and Jonathan Lees)

The 1992 M6.1 Joshua Tree earthquake occurred about two months prior to the M7.4 Landers earthquake and was followed by nearly 6,000 M>1 aftershocks recorded by the permanent regional network and an 11-element portable array deployed by the Southern California Earthquake Center. This sequence defined a complex set of subsurface faults that included secondary structures that strike either sub-parallel to the Joshua Tree mainshock rupture or on relatively short, left-lateral cross faults that strike at high angles to the mainshock plane. Seismicity on this fracture network ceased in the hours prior to the Landers event and did not resume. Instead, the Landers mainshock appears to have caused the activation of a new fracture network located farther west, that intersects the previous Joshua Tree activity in the area of the Joshua Tree mainshock. Much of this later activity coincides with a first-order discontinuity in 3-D velocity structure imaged by tomographic inversion of P-wave arrival times [Lees and Nicholson, 1993]. The Joshua Tree data thus provides important information on the pattern of subsurface stress and strain, and how it changed with time, before and after the Landers mainshock. The large numbers of earthquakes, the wide variation in focal mechanisms observed, and the complex pattern of subsurface faults involved, makes the Joshua Tree earthquakes an ideal data set to examine in more detail using the SCEC portable digital data and a new enhanced, interactive 3-D color graphic program -- Xmap8. Comparison of arrival times hand-picked from the portable data at Scripps (UCSD), ICS (UCSB) and Yale indicates that ~10% of the data are still susceptible to large timing errors. To remove large systematic errors from the portable phase data, a cluster analysis was performed; individual phases that moved an event epicenter beyond the cluster radius of 0.7 km or increased the RMS error by more than 0.04 were removed from the relocation procedure. If both portable and permanent network data are used relocated hypocenters are typically deeper and located farther south and west. Polarities of the vertical components at the portable stations were also found to be reversed. Revised focal mechanisms with 15 or more first-motions were determined for 1,484 Joshua Tree events (23 April to 28 June). Relocated hypocenters and revised focal mechanisms were then used to assess the pattern of subsurface active faults in the Joshua Tree area. Faults were identified by alignment of nodal planes and hypocenters in both space and time using Xmap8. Important questions Nicholson, Ely, and Lees hope to answer are:

(1) What are the orientations and geometry of faults activated in the Joshua Tree area before and after the M7.4 Landers mainshock? (2) What is the kinematic pattern of subsurface slip vectors? (3) How does this pattern relate to long-term accumulations of geologic strain, or to dislocation strain changes inferred for the Joshua Tree and Landers main shocks? (4) Is there any systematic stress change using focal mechanisms in the Joshua Tree area before and after the M7.4 Landers main shock?

Through this research many things may be concluded. Analysis of the SCEC portable digital data indicates that timing problems can be largely overcome and that the data are extremely useful for increasing model and structure resolution. Also, Xmap8 proved to be an effective analytical tool in helping to organize large numbers of hypocenters and focal mechanisms (that occurred in a relatively small geographical area) in to recognizable patterns of subsurface faults. The Joshua Tree sequence is largely composed of predominantly strike-slip events that typically strike either subparallel or at high-angles to the Joshua Tree mainshock rupture plane. The main north-south structure within the Joshua Tree area is composed of en echelon fault segments that typically strike slightly west of north. Several of these strike-slip fault segments are actually curved when viewed in cross section; this includes the Joshua Tree mainshock fault plane. In addition, second-order faults that dip at moderate-angles exist within this fracture network. The localization of many normal and reverse earthquakes is consistent with kinematic patterns of regional right-lateral shear strain.

Seismic Behavior and Fault Geometry of Blind Thrusts: Analysis of Structure in the Central Santa Barbara Channel (Craig Nicholson and Marc Kamerling)

Detailed cross sections constructed across the central Santa Barbara Channel using deep drill-hole and multi-channel seismic (MCS) data show that the Oak Ridge trend consists of folding above a steeply south-dipping reverse-separation fault. In one well (231 #5), Monterey Formation is steeply-dipping and exhibits over 2500 m of vertical separation between repeated sections. Dipmeter logs from several wells show increasing dip with depth and proximity to the Oak Ridge fault. Wells that penetrate gouge zones, repeated sections, and abnormally thick San Onofre Breccia, Vaqueros and Sespe formations also support the interpretation of a south-dipping fault and steeply-dipping to overturned strata. This deformation is not accurately reflected in the seismic data because MCS data are incapable of imaging such steep dips. High-resolution seismic data do show, however, that the Oak Ridge fault offsets a near sea-bottom unconformity. This, plus recent earthquake hypocenters that align along a south-dipping structure, suggest that the Oak Ridge fault is an active fault and not simply an "active axial fold surface." These observations are inconsistent with models which infer only growth folding above active low-angle thrust faults that dip north. These models assume that structure in the Santa Barbara Channel is 2-D, that formations are uniform in thickness, that near-surface dips can be projected to depth as constant dip panels, that strain is uniform and constant with time, and that there is no motion in or out of the plane of the cross section. These assumptions are not appropriate for the Santa Barbara Channel where geologic structure is inherently 3-D and exhibits considerable variation along strike, where strain has been partitioned between high-angle and low-angle structures, and where more recent faults and folds are strongly controlled by earlier normal-separation faults of Miocene age, which have subsequently been reactivated and likely rotated. These observations of an active, reverse-separation fault along the Oak Ridge trend in the Santa Barbara Channel could significantly alter the estimation of earthquake and tsunami hazards along the south coast of California.

Structural studies in the southern California offshore region (Christopher Sorlien)

Christopher Sorlien has been working on several projects related to the deformation of the California continental margin in the last 20 million years (Ma). One field-based project determined that the last motion on faults on Santa Cruz and Santa Rosa Islands was mostly horizontal. On eastern Santa Cruz Island and east of Anacapa Island, much of the late Quaternary activity has been on faults which appear minor in Miocene rocks. With the assistance of Erick McWayne, a deep multichannel seismic reflection profile (USGS-103) was created. From this profile reflections were detected that originated in the lower crust (~15-20 km depth) and were disrupted along the southeast projection of a former microplate boundary known as the Morro fracture zone. If this disruption is indeed related to the Morro fracture zone, then important predictions can be made concerning motions on faults. Additional work with Ken Bird and Lynn Tennyson of the U. S. Geological Survey as well as Ron Heck, an oil industry consultant, detailed the examination of both the timing and nature of deformation during the last 20 Ma. Extension faults which were active during Miocene time (25-5 Ma) were imaged on USGS-103 and other profiles. Compression folding during Pliocene (5-2 Ma) and later time turned basins into anticlines. Furthermore, a fault block model for rotation of the crust during the last 19 Ma was developed with Craig Nicholson and Bruce Luyendyk. Since both the shape and size of fault blocks is identical at 19 Ma and the present specific predictions may be made about the deformation. About 350 km of displacement between the Peninsular Ranges and the Pacific plate includes a large component of extension. A trigonometric equation demonstrates that the maximum possible rotation rate of crustal blocks is expected to decrease with time. Results of this project indicate that most of the closing of Santa Barbara Channel has not occurred, and is probably not occurring, beneath the central part of the Channel. Instead, it must be occurring near the northern Channel Islands and/or near the mainland Ventura to Goleta coast. Western Santa Barbara Channel may be closing much more slowly than is the case farther east. The studying of the deformation of the Santa Barbara Channel is an ongoing project associated with Bruce Luyendyk, Scott Hornafius, and Erick McWayne.

Nearfield Geodetic Investigations of Strain Across Faults in Southern California (Arthur Sylvester)

Sylvester focused the 1993-94 program of repeated surveys across active and potentially active faults upon the 170 km-long creeping segment of the San Andreas fault. Sylvester and his crew re-surveyed nine arrays between Cholame at the south end of the segment to San Juan Bautista at the north end. They also re surveyed arrays in Indian Wells Valley and at the southern of the San Andreas fault to search for any effects that may ensue there as a result of the 1992 Landers earthquake. Lastly Sylvester et al. re-surveyed arrays in the Mammoth Lakes array as part of a broader U.S. Geological Survey program to maintain a watch on the volcano-tectonic activity there. From this research Sylvester concludes that arrays in the midsection of the creeping segment of the San Andreas fault lack any indications of vertical displacement associated with a maximum horizontal creep of 34 mm/yr. At the ends of the creeping segment, however, where the horizontal creep decreases to 4-7 mm/year, Sylvester et al. measured vertical displacements of 40 mm in 7 years at the south end, and 80 mm in 18 years at the north end. They suspects that these vertical displacements are tectonic, but a nontectonic cause cannot be ruled out. Furthermore, no unusual vertical or horizontal displacements were measured in fault crossing arrays in Indian Wells Valley or at the southern end of the San Andreas fault. An L-shaped tilt array in the Mammoth Lakes area continues to tilt away from the inferred center of inflation in Long Valley caldera, but vertical displacement across the Hilton Creek fault in McGee Creek has ceased since accumulating 5 mm of normal offset in 12 years following the 1980 earthquakes. In the future, Sylvester intends to expand the coverage of active tectonic structures, especially in southern California, including and especially the frontal faults of the San Gabriel Mountains, and folded Quaternary strata in the central Mojave Desert by establishing new surveying arrays across them.

Aseismic Creep and Crustal Deformation of Large Normal Faults: Precise Leveling Across Teton Fault, Wyoming (Arthur Sylvester)

Sylvester and his student crew completely re-surveyed 50 permanent bench marks in the 22 km-long line across the Teton fault in Grand Teton National Park, Wyoming. The standard deviation of the survey is 5 parts in 10 million. The pattern of vertical displacement obtained in 1993 does not resemble anything obtained in the surveys of the line in 1988, 1989, and 1991. Instead, the valley segment of the line tilted 6 mm *eastward* and away from the Teton Range, opposite to the direction of tilt in previous surveys, opposite to that recorded over geologic time by the slope of alluvial surfaces, and opposite to that typically evinced adjacent to major normal faults. Thus, they concluded provisionally that the tilt is *nontectonic* and perhaps related merely to lowering of the water table in response to recent decreased precipitation. If that is true, then the symmetry of the 1993 displacements indicates that they have measured only one-half of the subsidence pattern. In the future, Sylvester plans to test this hypothesis regarding the hydrologic effects on the pattern of displacements and inferred tilt. Additionally, Sylvester intends to extend the line of bench marks eastward completely across the valley to bedrock in the Gros Ventre Mountains. Thus, they will extend the line 7.8 km from the Snake River to Shadow Mountain by adding 20 new permanent bench marks and surveying them in the summer of 1994. (In fact this work was completed successfully as of the date of this writing.) Furthermore, Sylvester and his crew intend to seek funds to re-level the entire line in 1995 or 1996 to ascertain the stability of the 20 new bench marks and to lengthen the duration of observation of the displacements in our search for tectonic creep on this spectacular fault.

High-Resolution Global Body Wave Waveform Inversion for the Mantle and Core, Large-scale Oceanic Upper Mantle Structure and Constraints on Ridges and Hotspots, and Global Three-Dimensional Structure of the Outermost Core and Mantle obtained from long-period seismic data (Toshiro Tanimoto)

All three grants concern attempts to study large-scale interior structure of the Earth in hopes of coming to a better understanding of large scale tectonics (motion) of the Earth. Papers detailing this research were presented at AGU (San Francisco), one with collaboration with Keith Dinger (now at UCSD) and the others with Sharon Kedar, Shingo Watada and Monica Kohler at Caltech. Four papers were published in 1993-1994 and four were accepted. Tanimoto is now in the process of producing an even bigger data base to image the earth's interior in more detail. Within a few years, Tanimoto expects to obtain a much better earth model than is currently available.

2. Crustal Materials

Personnel: C. Balzer, J. Bryce, K. Kummer, B. Patrick, F. Raia, **F. Spera***, D. Stein, A. Trial, W. McClelland, J. Vogl (* Agenda coordinator)

Thermomechanical Development of the Internal Zone and Tectonothermal Evolution During Collisional Orogenesis (Brian Patrick, William McClelland and James Vogl)

Patrick's group is examining processes affecting crustal materials that have been subjected to continental collision. Specifically, the group is focusing on metamorphism and magmatism in northern Alaska to determine the connections between deep burial of crustal materials, continuing deformation and final unroofing (exhumation). Structural, petrologic, and geochronologic data indicate that the initial collisional phase took place at ~165 Ma and was accompanied by high pressure metamorphism and intense northward ductile flow associated with crustal shortening. This contractional regime continued for ~40 m.y.; flow continued in northward direction while the deeply buried rocks were imbricated and emplaced at a higher crustal levels. Juxtaposition of rocks from different crustal levels attest to the complex interplay between continuing contraction and partial exhumation. In one study area, rocks that were once metamorphosed at high pressures (>12 kbar) and relatively low temperatures 450-500°C at 165 Ma were thermally overprinted to 525-550°C at 6-8 kbar (at 105 Ma). This rock package was then emplaced at a higher structural level, leading to a preserved inverted temperature gradient. This scenario occurred during continued contraction of the entire collisional belt at all crustal levels. Patrick's group is currently attempting to further refine the mechanical linkage between the internal metamorphic zone of the mountain belt with the brittlely deformed external zone (fold and thrust belt). The approach, in which the group combines field studies with structural, geochronological and petrological analysis should lead to an improved actualistic model of the tectonic evolution of northern Alaska as well as providing a framework for general processes associated with continental collision.

Physical Modeling of Sedimentary Basins, Magma Mechanics, and Molecular Dynamics of Geological Solutions (Frank Spera, Connie Balzer, Dan Stein and Alain Trial)

This project examines the transport of mass, momentum, heat and chemical species at both macroscopic and microscopic scales in the crust which is vital to an understanding of the evolution of magmatic, hydrothermal and sedimentary basin systems. This work involves a number of sub-projects including study of the properties of sodium aluminosilicate melts by laboratory and numerical experiment, investigation of the dynamics of magma origin, ascent, and withdrawal, and study of the dynamics of thermohaline porous media convection.

Spera's research yielded laboratory results indicating that all melts in the system $NaAlSiO_4$ - SiO_2 are examples of strong fluids characterized by Arrhenian activation energies for viscous flow which are independent of temperature but which depend on composition (E_a (silica) ≈ 515 kJ/mol; E_a (nepheline) ≈ 320 kJ/mol). Molecular Dynamics Simulations indicate that many thermodynamic and transport properties may be adequately predicted using pairwise-additive effective pair potentials. Activation energy for oxygen self diffusion in nepheline melt is circa 150 kJ/mol at 3GPa and 2500 kelvins. Ionic conductivity of $NaAlSiO_4$ melt is about 100 mho/m with an activation energy of 65 kJ/mol. This is similar to the MD and laboratory value of 58 kJ/mol for sodium self-diffusivity.

Additionally, magma withdrawal calculations enable one to forward model the removal of magma at high rates of discharge through conduit systems connected to density- and viscosity-stratified magma bodies within the crust. Extensive results have been obtained and are published in the Journal of Geophysical Research. Non-Newtonian magma properties have a demonstrable effect on magma withdrawal. Finally, time-dependent simulations of thermohaline convection in fractured (equivalent) porous media show that, at fixed porosity and thermal Rayleigh number, as the salinity Rayleigh number (Rs) increases the dynamics change from convective steady-state at low Rs to chaotic flows at higher Rs and finally to conductive steady state at the highest Rs. The eulerian chaos observed may be relevant to the interpretation of fluid inclusions in that fluid salinities at a fixed location may vary chaotically in time.

Magma Transport Phenomena: Microscopic to Macroscopic (Frank Spera, Federica Raia and Dan Stein)

This project involves research in magma transport phenomena at both the macroscopic and microscopic scale. Work at the macroscopic scale utilizes a sophisticated computer code that faithfully captures details of convection in two-component melts undergoing phase change. The work includes: 1) up-grading code to 3-dimensions with some technical improvements including more realistic two-phase non-Newtonian rheology, 2) expansion of code capability to multicomponent natural systems using best thermodynamic database available, 3) analysis of the 'crustal anatexis driven by basaltic underplating' paradigm, 4) study of the behavior of silicate mush piles, specifically the spontaneous development of melt channels within the mush during cumulate formation 5) modeling of radial-zonation of Sierran-type granitic plutons. At the microscopic scale, the method of Molecular Dynamics will be used to study the transport properties (trace and chemical diffusion and melt viscosity) of melts in the systems Na_2O-SiO_2 and $NaAlSiO_4$-SiO_2 at high temperatures and pressures. In particular, Spera's research group will attempt to compute the full $(n-1)^2$ diffusion matrix for chemical diffusion in the system Na_2O_2-Al_2O_3-SiO_2 at geologically relevant conditions of temperature and pressure using the linear response theory embodied in the Green-Kubo relations.

Convective Dynamics Beneath Crustal Oceanic Spreading Centers (Frank Spera, Kristen Kummer and Alain Trial)

This is a project to study by numerical simulations the convective dynamics of three different portions of the crust beneath oceanic spreading centers. This two year project has three components: (1) Two- and three-dimensional modeling of thermohaline convection in the fractured oceanic crust with anisotropic permeability and variable fluid properties (2) Two- and three-dimensional modeling of melt convection within a sub-axis melt lens with a focus on mixing dynamics and its relation to observed geochemical segmentation (3) the interface dynamics between magma in the melt lens and the underlying low melt fraction mush. Advanced graphics and visualization techniques will be employed in order to comprehend better the transient physical-chemical processes associated with oceanic spreading center hydrothermal-magmatic systems.

3. Earthquakes

Personnel: **R. Archuleta***, J. Lees, G. Lindley, A. Martin, D. Oglesby, C. Nicholson, P. Rodgers, J. Steidl, S. Swain, Alexei Tumarkin, Alla Tumarkina (*Agenda coordinator)

Garner Valley Downhole Array (GVDA) (Ralph Archuleta, Jamie Steidl and Alexei Tumarkin)

This project comprises downhole accelerometer array studies at Garner Valley, California, sponsored by the Office of Research, U. S. Nuclear Regulatory Commission, the French Commissariat à l'Energie Atomique and by the Electrical Power Research Institute. This project started in 1987 and was recently funded through November 1995. It involves the installation, maintenance, data acquisition and analysis of 10 dual-gain accelerometers, of which five are placed in a downhole array to a depth of 220 m and five placed in a linear surface array. The basic objective is to understand how the near-surface geology affects the amplitude and duration of seismic ground motion, especially strong motion. From its installation in July 1989 through May 1994, 761 earthquakes have been recorded at GVDA including the April 1992 Joshua Tree M 6.1 earthquake, aftershocks of the Landers M 7.3 and the January 1994 Northridge M 6.7 mainshock.

In the Fall of 1992, Steidl began collecting data from boreholes and surface sites in the vicinity of the Garner Valley Downhole Array (GVDA) to examine the variation in the bedrock "reference" motion. Many studies of seismic zonation consider the site amplification at a particular location with respect to some "reference" site, usually a bedrock site. An assumption is made that the site response of the bedrock site is negligible, unity amplification over all frequencies of interest. Steidl has been collecting borehole data at GVDA as well as Pinon Flat, approximately 30 km from GVDA, and at Keenwild, approximately 7 km from GVDA, as well as surface bedrock sites to examine this critical assumption.

GVDA Deep Hole (Ralph Archuleta, Alexei Tumarkin and Jamie Steidl)

The Office of Research, U. S. Nuclear Regulatory Commission and the French Commissariat à l'Energie Atomique funded a proposal to drill a 600 m deep hole at Garner Valley. The primary purpose is to correlate the hydrologic response with earthquake generated ground motion. While complementary to the existing GVDA project, this project requires a new direction in equipment design. The hole has been drilled to 520 m (1706 ft) and is vertical within 1.5°. Numerous logs of the physical properties of the hole have been taken by personnel from the U.S. Geological Survey (Water Resources Division) and the Institut Physique du Globe, Paris. Based on these logs the depths for the placement of the instrumentation have been determined. The basic instrumentation consists of accelerometers at 500 m, dynamic pressure transducers at 420 m and 330 m, and 5 quasistatic pressure lines that sample the isolated regions of the borehole. The string of instruments will be placed in the hole in March 1995.

Rupture complexity of the Northridge earthquake (Ralph Archuleta, Alexei Tumarkin and David Oglesby)

This project focused on the source complexity of the Northridge mainshock by a dual approach to inversion for the slip and rupture histories. First, the isochron method of Spudich and Frazer (1984) was used to generate synthetic high-frequency Green's functions. A variety of source time functions were used to determine the best fit to the data. The overall geometrical shape of the rupture area can be described as an trapezoid widening up-dip, consistent with the aftershock locations from both the Caltech catalog and Mori (1994). Under a constant stress drop hypothesis the final slip is proportional to the rise time of the subfault slip-rate function, resulting in a simple iterative procedure for a simultaneous inversion for the slip and the rise-time. The project group also perform a truly non-linear inversion allowing for a variable rupture velocity and rise-time on the fault. Every inversion procedure should include an objective testing of quality of fits such as calculating the variance reduction for each component of observed recordings (Cohee and Beroza, 1994). This determined that it is difficult to distinguish between models of rupture with different degrees of sophistication- (variable rupture velocity, rise-time, etc.). Low-passing the data and calculating Green's functions up to a certain frequency limits the resolution of any method to this upper frequency. Therefore any method that uses only frequencies below 1 Hz should not be able to resolve for rise times less than 1 s. The project incorporates both the high-frequencies and the site response into the inversion scheme by utilizing empirical Green's functions (EGF) - recordings of aftershocks. To obtain true Green's functions, source time-functions should be deconvolved from the data. Without deconvolution one can use EGFs only below corner frequencies of the aftershocks. Digital data from the instruments co-located with permanent CDMG and USGS sites allows for the inversion in different frequency ranges.

How Earthquakes Produce Extreme Accelerations (Ralph Archuleta and David Oglesby)

A puzzling observation from some earthquakes is that extremely high ground accelerations (~1-2 g) may be recorded at certain accelerometers, yet nearby accelerometers record accelerations that are 3 to 4 times lower. The 1985 Nahanni, Canada and 1992 Petrolia, California, earthquakes provided examples of this phenomenon.

Oglesby and Archuleta have investigated whether this phenomenon is a result of constructive interference of waves leaving the fault. If constructive interference is the cause, it places severe constraints on how a segment of the fault must rupture. Moreover, the possibility of extremely large accelerations requires a particular station-source geometry. Preliminary numerical results have produced localized extreme accelerations that differ by factors of two or more between stations separated by less than 0.5 km, and by factors of 5 or more between stations separated by 1 km.

Southern California Earthquake Center (Ralph Archuleta)

The Southern California Earthquake Center is a NSF Science and Technology Center established in 1990. SCEC is comprised of 9 institutions involved in earthquake research in Southern California. ICS/UCSB activities fall into several categories: Portable Broadband Instrument Center (PBIC), Strong Motion Database (SMDB), Site Response Studies, Ground Motion Prediction, Earthquake Parameters and Educational Outreach.

In 1993-94 a major effort was undertaken following the January 17, 1994, M 6.7 Northridge earthquake. Archuleta and his team mounted a full-scale effort to deploy SCEC portable recorders/sensors in the epicentral region. Their efforts were coordinated with SCEC institutions and federal agencies. Eighty instruments were put into the field in the days following the earthquake; 17 recorders/sensors were directly maintained by ICS. The 4-5 gigabytes of data are being used in several research topics—inversion of the mainshock mechanism, fault structure beneath the San Fernando Valley, site response throughout San Fernando and Los Angeles basin.

Source Parameters of the April-May 1992 Joshua Tree, California Earthquakes (Ralph Archuleta and Grant Lindley)

Recordings of the magnitude 6.1 1992 Joshua Tree earthquake, its aftershocks, and one foreshock were studied in order to compare source properties of the earthquakes. The purpose of this study was to examine the scaling of source size between a main shock and its aftershocks and to determine if there is some property of foreshocks that can be used to identify them as foreshocks before the main shock occurs, which would allow a short-term prediction to be made in certain cases. The Fourier amplitude spectra of seismograms were modeled by computing least-squares best fits of earthquake models to the data. The parameters determined from the fits allowed the scaling of the earthquakes in the sequence to be compared. The results indicate a significant difference in source properties between the main shock and its aftershocks, suggesting that the main shock source process is fundamentally different from that of the aftershocks. There were no differences found between the foreshock and the aftershock sources, however, indicating that it will be difficult to identify foreshocks as such prior to the occurrence of a larger earthquake.

Analysis of Source Spectra, Attenuation, and Site Effects Using Broadband Digital Recordings from the National Seismograph Network (Ralph Archuleta and Grant Lindley)

This is a new project that will use data being collected by the National Seismograph Network throughout the United States. The emphasis of this work is to develop new methods for estimating ground motion from future earthquakes, especially in the central and eastern United States, where a paucity of data has hampered the development of these methods. The Fourier amplitude spectra of earthquake recordings will be studied to develop models of the spectra. These models will then be used to estimate important ground motion parameters, such as peak ground acceleration, peak velocity, and response spectral amplitudes from future earthquakes in the central and eastern United States. These results will be important in assessing the safety of power plants and other structures in the event of a moderate to large earthquake.

Seismology Curriculum Using CUBE for Santa Barbara County Schools (Ralph J. Archuleta and Robert Pizzi)

The purpose of the project was to write a two week module on seismology utilizing the CUBE system and to construct a seismic display which included the CUBE hardware and a recording seismograph at Bishop High School in Santa Barbara, California. The intent was to stimulate interest in seismology among students, staff, parents, the general public, and the local media.

Bishop Garcia Diego High School provides a high school education to a broad base of students. The school is comprised of about 384 young men and women from various backgrounds. The majority of students are of Mexican-American descent from all income ranges. The school curriculum prepares students to continue their education at either two or four year institutions of higher learning.

During the summer of 1994, part of an administration office was re-modeled to house the pen and ink seismograph and the CUBE system hardware. The glass encased, oak wood trimmed display is located in the main corridor where it can be viewed by the largest number of people. A remote keypad is available (four keys only) for the inquiring person to interact with the CUBE.

Additionally, during the summer, equipment was purchased that was reviewed for use in the teaching module. This included various laboratory hardware, fault models, an instructional video and laser disc, seismograms from the 1964 Alaska quake, model of a seismometer and an earthquake watch kit. This equipment has been reviewed and those found suitable were ordered for the classroom.

The teaching module is in its draft mode. Parts of the module have been tested on science club participants who are doing some data collection with the CUBE so they may enter a project in the Santa Barbara County Science Fair.

The course module will be finished by the end of this semester (Jan. 95) and offered second semester in the earth science part of the Physical Science course and in the waves portion of the PSSC Physics course.

During the second semester, communication will be made with the Santa Barbara City High Schools (Phase II)to discuss the introduction of the module into their programs and the prospects of getting a CUBE at these schools.

In the module, the CUBE system will be used to monitor seismic activity in the Santa Barbara area as well as the Los Angeles basin and vicinity. Students will use maps to plot events. Long term projects would include: seismicity vs. location, magnitude vs. location, determining p-wave velocity of recorded events, frequency of events, etc.

Recently, we have experienced a number of small local seismic events that were felt by the residents of Santa Barbara and Santa Ynez. The local ABC affiliate, KEYT, came out to the school with a camera crew. The newscaster interviewed me and two students and shot some video of both the seismograph and the CUBE. The news crew was quite impressed. An invitation was extended to come to the school any time in a crisis to shoot the CUBE. (The interview was precipitated by the M=8.2 Kurile quake and subsequent tsunami warning.) The video aired three times that evening on the 5, 6, and 11 o'clock news.

3-D Dynamic Rupture Models of Interacting Fault Segments (Grant Lindley)

This project has recently undergone a change of principal investigators and is still in its beginning stages. The goal is to examine how parallel fault segments interact during an earthquake and how that interaction affects ground motion. Preliminary computer modeling is just now being completed. The research will examine how complexity of a fault can be observed in seismograms and whether this complexity can significantly affect the strong ground motion produced by earthquakes, which is the cause of most earthquake-related damages. The results of the computer modeling will be compared to seismograms from previous earthquakes, including the 1966 Parkfield earthquake and the 1992 Landers earthquake.

Calibration of sensors used in SCEC/LARSE '93 experiment (Aaron Martin and Pete Rodgers)

The Southern California Earthquake Center/Los Angeles Regional Seismic Experiment (SCEC/LARSE), managed and organized by UCLA, utilized over two hundred seismic components in its month long deployment. In late December 1993 and early January 1994, the Portable Broadband Instrument Center (PBIC) began the process of calibrating the sensors used in the experiment. Some preliminary tests at the PBIC indicated that it might be possible to calibrate sensors without calibration coils by applying step functions directly to the signal coils. These preliminary tests showed good results for the resonant frequency and damping parameters, but there was no basis for calculating the amplitude response. By the end of the LARSE experiment the PBIC had a simple system set up that would allow a calibration step response to be recorded directly from the signal coil. In theory it appeared that amplitude information could also be derived from the recorded step response. Although not completely satisfied that amplitude information could be successfully derived from signal coil step responses, the PBIC proceeded to record step responses for all the sensor components. Preliminary results showed clearly that the calibration project was worthwhile due to several problems or differences that were spotted almost immediately.

Los Angeles Basin Microzonation (Jamie Steidl)

This year marks a good start for the LA Microzonation project. The project objective is to collect seismic data from sites throughout the Los Angeles metropolitan region for seismic hazard analysis. It has long been known that each soil type responds differently when subjected to ground motion from earthquakes. Usually the younger, softer soils amplify ground motion relative to older more competent soils or bedrock. Our goal is to instrument different sites throughout Los Angeles to quantitatively measure this amplification of ground motion. After obtaining this data contour maps of amplification will be created to show regions where the seismic hazard is greatest due to amplification from the surface geology and sub-surface structure.

This past year five sites have been maintained. With the Northridge M6.7 earthquake and its aftershocks there was no shortage of data. Four of the sites recorded the January 17th mainshock on scale at distances as close as 14 kilometers and as far as 40 kilometers. ICS personnel spent a great deal of time out in the field collecting data. Over 6000 aftershocks were recorded. This data alone will keep this project very active in the upcoming year. Also, in the next year the project plans are to deploy a set of ten instruments provided by PASSCAL and five instruments from SCEC & CALTRANS for a 9 month period. These 15 sites will be located so as to help fill in the gaps where there is little or no previous seismic information about the amplification.

The 1993-94 year proved to be a busy one for this project and no doubt with the renewed funding for 1995 it promises to be another busy year in the future.

Prediction of Ground Motions For Large Earthquakes Using Observations Of Small Earthquakes (Alexei Tumarkin and Ralph Archuleta)

This project developed new methods of site-specific ground motion prediction in the time and frequency domains. A large earthquake is simulated as a composite (linear combination) of observed small earthquakes (subevents) assuming various functional models of the source time functions (spectra). Source models incorporate basic scaling relations between source and spectral parameters. Ground motion predictions are consistent with the entire observed seismic spectrum from the lowest to the highest frequencies avoiding deficiency in the vicinity of the target corner frequency. These methods are designed to use all the available empirical Green's functions (or any subset of observations) at a site. Thus a prediction is not biased by a single record, and different seismic wave propagation paths are taken into account. Any procedure of adding subevents in the time domain requires knowledge (or determination) of rupture times of subevents. Joyner and Boore [1988] recognized a major problem with using a uniform distribution of rupture times: the natural assumption of a constant rupture velocity leads to a significant underestimation of the main event's spectrum in the vicinity of the target corner frequency (by producing a local minimum of energy instead of a global maximum). As the spectral corner frequency acts as a source resonant frequency, any misfit to the spectral amplitudes near the corner frequency significantly affects the total energy in the computed time-series. This problem can not be overcome by allowing for different subevent sizes, but only by imposing a specific variation of the rupture velocity or of the stress drop. This project's time-series prediction algorithm is based on determination of a specific distribution of rupture times of subevents. This approach is an extension of the method proposed by Wennerberg [1990]. The method is completely empirical. It requires only four input parameters for the simulated large event: 1) seismic moment; 2) size of the rupture area; 3) location of the hypocenter; and 4) direction of rupture propagation. There are no other free parameters.

Maps Of Gross Amplification Factors For The LA basin (Alexei Tumarkin, Jamie Steidl, and Ralph Archuleta)

Site response studies should use both spectral and time-domain approaches. The analyses in the frequency domain (spectral ratio method, cross-spectrum method, etc.) have an obvious limitation of completely disregarding such an important engineering factor as the duration of shaking. At the same time the response spectral ratio method takes more care of duration, but in a not very explicit manner. That necessitates finding a way to incorporate duration content. This new method developed through this project provides the amplification factor associated with signal's envelope. A direct comparison of envelopes of two recordings of ground motions at different sites seems impossible. Those involved with the project are attempting to rearrange amplitudes to produce an "equivalent" (in the sense of preserving absolute duration of shaking above an arbitrary amplitude threshold) envelope. Each given value A of the ordinate (observed amplitude) corresponds to the value of the abscissa D of this equivalent envelope, representing the total duration of shaking with amplitude greater than A. For equally spaced time-series this is easily achieved by sorting the initial envelope's amplitudes in a descending order. Next a duration-amplitude graph is generated which represents an inverse function to the cumulative amplitude-frequency distribution, suggested by V. Schenk (1985). Now there is a tool to study the amplification of envelopes of seismic signals by comparing amplitudes corresponding to the same absolute duration of shaking. Collected research demonstrates that in the range of duration of a prime engineering concern (0.1 - 10 s), the envelope amplification between stations with different site geology is approximately constant. This fact allows the introduction of a time-domain measure of a gross amplification of ground shaking as the average ratio of sorted envelopes between 0.1 and 10 s. The comparison of envelope ratios with response spectral ratios (5% damping) shows that the envelope method is not so sensitive to site and/or source resonances, at the same time providing amplification values consistent with those inferred from the response spectral method. In turn, the above described method was used to produce a map of gross strong ground motion amplification factors for the LA basin.

Results of Maps of Gross Amplifications Factors for the LA Basin were presented at the following conferences: 27th General Assembly of the International Association of Seismology and Physics of the Earth Interior (Wellington, New Zealand, January 1994 - talk delivered by Prof. Archuleta); and at a monthly seminar of the Southern California Earthquake Center.

4. Hazardous Waste Materials

Personnel: S. Cullen, G. Deane, **L. Everett***, J. Kramer (*Agenda coordinator)

Environmental Monitoring Systems Laboratory Las Vegas, Nevada (Stephen Cullen and Lorne Everett)

A three year cooperative agreement between the United States Environmental Protection Agency and the Vadose Monitoring Laboratory within the Institute for Crustal Studies at UCSB came to a successful conclusion in the Summer of 1993. The cooperative agreement resulted in the successful completion of the Ph.D. degree by Dr. John Kramer. In addition, the agreement resulted in the support of other graduate students working within the Vadose Zone Research Lab. The cooperative agreement resulted in the production of two books, participation in four international symposia, participation in six national symposia, involvement in four workshops, development of five ASTM National Standards, and the completion of greater than 15 professional papers. A major deliverable associated with the cooperative agreement is entitled "Permit Writers Guidance Manual for Monitoring Unsaturated Regions of the Vadose Zone at RCRA, Subtitle C, Facilities". This guidance document, authored by Stephen J. Cullen and Lorne G. Everett, has been forwarded to EPA headquarters for review. It is anticipated that this guidance document will appear next year as interim guidance and shortly thereafter will be mandated as a national requirement at hazardous waste facilities.

Sandia National Laboratory Research: Horizontal Neutron Moisture Logging As A Vadose Zone Monitoring Strategy (Stephen Cullen and Lorne Everett)

Both Cullen and Everett collaborated with scientists at Sandia National Laboratory to develop an approach for a long term vadose zone monitoring strategy at waste impoundments using horizontal neutron moisture logging (HNML) techniques. HNML provides opportunities to optimize monitoring networks in space and time. The technique is a non-destructive technique that gives real time results over spatially continuous transects. The low cost per sample event permits frequent monitoring that can be responsive to changing conditions and developing containment leaks. The techniques developed in the project accommodate frequent sampling resulting in statistically useful data sets such that the HNML monitoring network can be optimized by adjusting sampling positions or schedules to account for correlation lags. While the focus of the research was on developing an approach generally applicable to many waste management applications, the technique allows full spatial coverage of a vadose zone monitoring network beneath a waste facility in specific cases and for particularly dangerous contaminants. Based on the results of this research, a logical approach is now available to developing risk-based monitoring network designs which prioritize vulnerability to high-volume and far-reaching hydrologic release events by focusing first on engineering design weaknesses and, secondly, on natural flow pathways predicted from geologic information. The approach is iterative in which monitoring procedures and data are used as a feedback mechanism to fine tune the monitoring network to ambient conditions at the site.

Lawrence Livermore National Laboratory Research: Diffusion Of Tritiated Water Vapor In

Unsaturated Soils (Stephen Cullen and Lorne Everett)

Tritium is a naturally occurring isotope of hydrogen within an atomic weight of three. Since the introduction of nuclear devices, the atmospheric concentration of tritium has increased by approximately three orders of magnitude with current annual inputs of tritium attributable mostly to nuclear reactors. Additionally, nuclear research has created large depots of stored tritiated water most of which is stored in underground storage tanks. As a radioactive isotope in liquid form, tritiated water presents a significant mobile environmental hazard at numerous sites around the world. Cullen collaborated with scientists at Lawrence Livermore National Laboratories (LLNL) to quantify a previously unmeasured transport mechanism of tritium: diffusion of tritiated water vapor through the subsurface environment. ICS researchers designed an experimental apparatus which allowed the measurement of tritiated water vapor diffusion in porous media while allowing careful control of soil moisture content. The experiments resulted in precise measurements of tritiated water vapor diffusion coefficients in a range of soil types over a range of water contents. These kind of measurements are previously unreported in scientific literature. In addition to the experimental work, Cullen and Everett also investigated and compared differences between tritiated water vapor diffusion rates predicted by theoretical models to their experimental results. Interestingly, theoretical models predict faster transport rates than are actually observed in an experimental setting. Further work is planned by ICS and LLNL researchers to provide explanations to these differences.

Vadose Zone Book Project (Stephen Cullen and Lorne Everett)

Cullen and Everett acted as coeditors in the development of the upcoming Handbook of Vadose Zone Characterization and Monitoring. The book is a compilation of topics on the basic principles of vadose zone hydrology and prevalent monitoring techniques. The book also prints case studies of actual field experiences at sites around the nation. The book is intended to provide new practitioners with information to fully understand the principles, advantages, and limitations of various vadose zone monitoring techniques that are available.