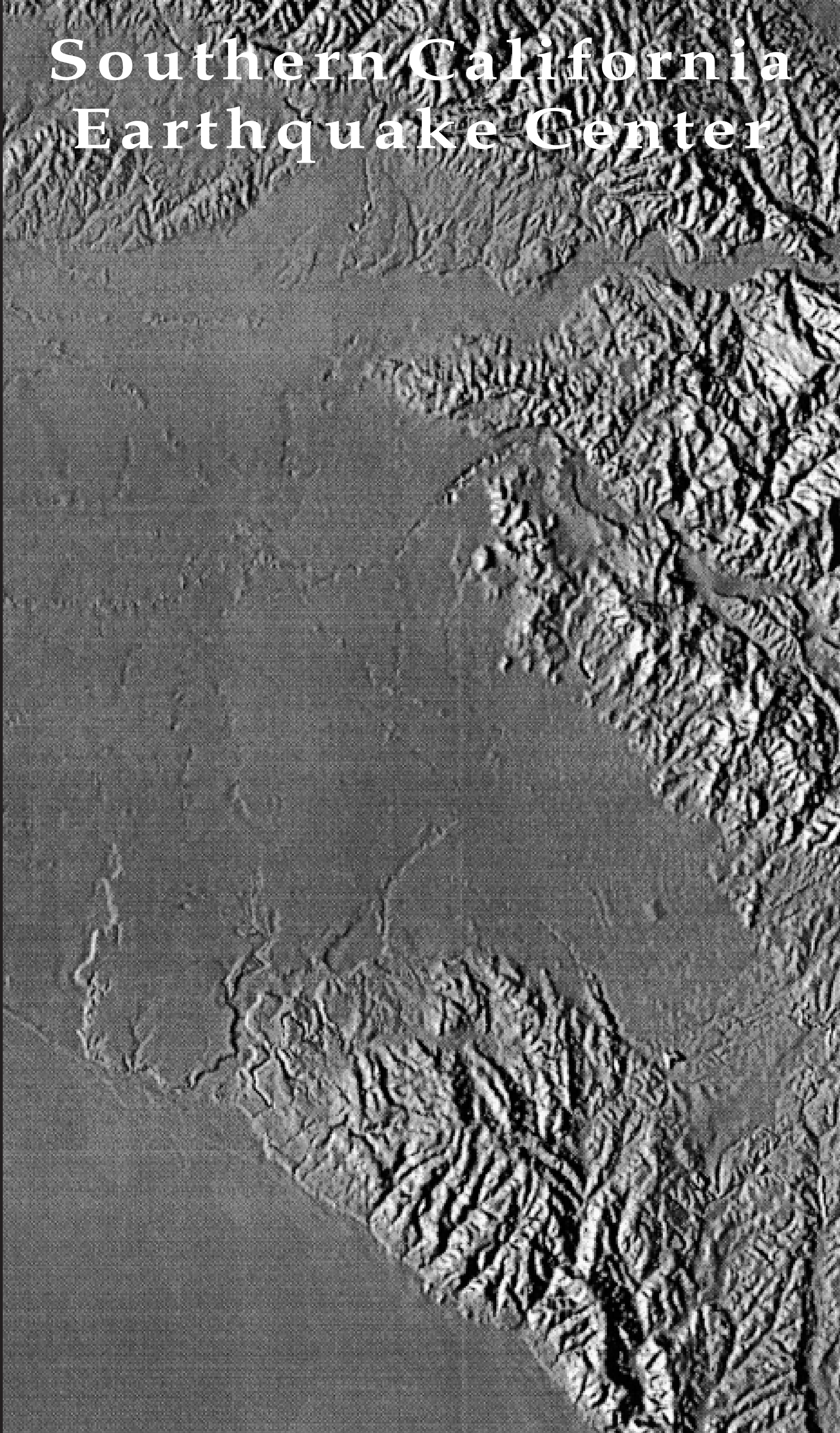
Quarterly Newsletter
Volume 4, Number 2

Southern California Earthquake Center

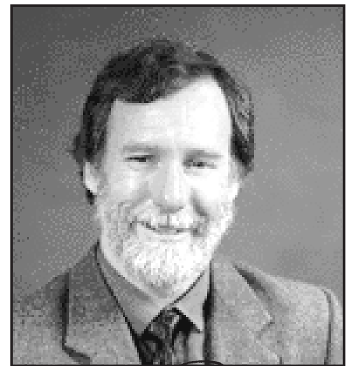


SCEC

From the Center Directors . . .

Outreach Program Just Gets Better

Center Director



Science Director

Recently the seismicity and GPS web-based science education modules have been receiving kudos left and right.

The Center's Outreach Program under Jill Andrews' directorship just keeps getting better and better. It is one of the Center's real success stories. And of course it doesn't hurt having Mark Benthien and now Sara Tekula on board either!

Although many of the program's activities have been cast in starring roles, recently the seismicity and GPS web-based science education modules have been receiving kudos left and right.

Many thanks for this must go to John Marquis and Katrin Hafner (nurtured by Egill Hauksson) at Caltech for their efforts on the seismicity module, and Maggi Glascoe and Andrea Donnellan at JPL for their work on the GPS module. The modules are products of two world-class laboratories whose research missions are in the same areas encompassed by the modules.

We believe an important product of SCEC's education effort is development of web-based education modules in the Center's research areas. The two modules are intended to introduce high school and lower-division college students to earthquake-related topics and provide them with activities that aid in learning.

Working with the teachers was an especially rewarding experience. Not only did I pick up a couple of pointers useful in my own teaching, but also I learned first-hand something I had sensed for a long time . . .

The sites under construction have attracted enthusiastic interest from teachers and professors who would like to use portions in their curricula, even before the modules have been completely reviewed for scientific accuracy and adherence to national and state education standards.

On May 9, I participated in a workshop hosted by Jill to bring together a group of teachers and curriculum specialists from California who volunteered to give us an initial assessment of the seismicity module and help us establish a baseline for further development of the module in accordance with the education standards. It was clear there was considerable interest in both the material and how it was packaged.

Working with the teachers was an especially rewarding experience. Not only did I pick up a couple of pointers useful in my own undergraduate teaching, but also I learned first-hand something I had sensed for a long time—namely how difficult it really is to bring meaningful science instruction to the K-12 classroom. The material must be organized to fit with the education standards; there must be a story line or statement of the unifying theme and scientific concepts being addressed that meshes with the relevant scientific pedagogy; and module developers must be able to articulate a vision that will promote and encourage optimal use of the final products.

So I want to thank publicly the SCEC outreach team, the module developers, and the participating teachers and curriculum specialists for working toward the successful completion of the modules. This is truly outreach at its most fundamental and most critical in the long term. Despite the hard work, it is also potentially the most widely effective outreach we can do. I hope the tremendous amount of work involved does not deter us from moving ahead on additional modules in the future.

—Tom Henyey

SCEC-Sponsored Workshop

Stress Triggering Conference Opens Window to Master Model

By Ross Stein, USGS Menlo Park

SCEC sponsored the conference "Earthquake Stress Triggering, Fault Interaction, and Frictional Failure" on June 8-10 in Carmel. Convened by Ross Stein, with financial support from the USGS, the conference hosted 57 participants.

In addition to the usual suspects, six came from Europe, and seven graduate students attended. This was the second stress triggering conference convened by SCEC. Thanks to Ruth Harris and Joan Gomberg, the collection of 13 papers growing out of the first conference will appear in *JGR* this fall.

Since its inception, SCEC has catalyzed research on how one earthquake sets up the next by the transfer of stress. If demonstrated, such a phenomenon could provide part of the foundation for the mythical Master Model. More than any other events, the 1992 Landers and 1994 Northridge earthquakes and their aftershocks have fueled studies of stress triggering.

SCEC's role has been important not only because it coordinated these earthquake investigations, but because SCEC encouraged people from different disciplines and viewpoints to attack these problems and to present their ideas and hash out their differences in intensive workshops and SCEC's annual meetings.

At the Carmel conference there was palpable excitement because, as more evidence pours in, some tenets of stress triggering are proving durable. Earthquakes in sequences tend to promote each other successively. Aftershocks tend to occur where the Coulomb stress is calculated to have risen and tend to be absent where it has dropped.

Uncertainty in these calculations, such as the friction coefficient, is beginning to diminish; the major faults exhibit very low values of friction, and minor faults show very high values. At the meeting, there was also frustration that other elements of stress transfer continue to baffle or elude us. Foreshocks, for example, just don't seem to stress the site of mainshocks. There are huge gaps in our understanding of dynamic stress triggering and transient stressing, including why friction can vary so strongly between two faults.

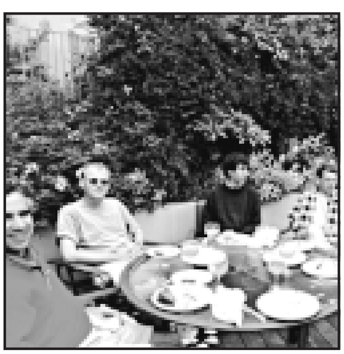
Earthquake Sequences

In closely spaced sequences, one shock generally stresses the site of the next (as shown in talks given by Massimo Cocco and Concetta Nostro; Deng and Lynn Sykes; Ruth Harris and Bob Simpson; Jian Lin), and these effects are visible for years and perhaps decades.

For continental thrust, normal faults, and young strike-slip faults, there is a strong sensitivity to unclamping; on major strike-slip faults, there is a strong sensitivity to shear stress change (Tom Parsons, Ross Stein, Bob Simpson, Paul Reasenberg). This suggests that faults may become frictionally weaker with age, cumulative slip, or length. Could this be the result of a slip-rate or healing-rate dependence (Chris Marone), material properties in evolved faults (Mike Blanpied, and Dave Lockner), large faults behaving more brittlely (Tom Heaton), rate and state constitutive behavior (Jim Dieterich), or poroelastic effects (Steve Miller, Jim Rice, and Paul Segall)?

Aftershocks show a strong sensitivity to Coulomb stress changes. Even more convincing, the seismicity rate jumps by an order of magnitude where Coulomb stress is calculated to rise by 1 bar after an earthquake and the seismicity rate drops where stress decreases (Shinji Toda, R. Stein, and J. Dieterich). This stress-change dependence of seismicity is seen both on the major faults and throughout the crustal volume surrounding a major earthquake (Greg Anderson, Jeanne Hardebeck) and is mirrored in the creep response of major faults (Roland Bürgmann). Although aftershocks are small, they are abundant and thus furnish good statistical tests of stress transfer, although perhaps not good enough to satisfy Yan Kagan.

Although large earthquakes tend to be preceded by an increasing rate of smaller shocks over a wide area encompassing the future earthquake (Charlie Sammis), foreshocks do not appear to promote failure at the future hypocenter (Ellsworth, Doug Dodge, and Greg Beroza). A break in the clouds is hinted by the result that the Lake Elsman "foreshocks" appear to have unclamped the Loma Prieta fault where it subsequently slipped the most (Hugo Perfettini, R. Stein, R. Simpson, M. Cocco).



Photos: Tom Henyey

Patio talk. Left: Ross Stein, Roland Bürgmann, Fred Pollitz, Bill Foxall, Oona Scotti. Middle: Monica Stein, Sharon Lack Stein, Nano Seeber, Mark Petersen, Dave Schwartz, Tom Rockwell. Right: Jim Rice, Yan Kagan, Charlie Sammis, Chris Marone , John Rundle.

Network and historical catalogs permit long-term statistical tests of stress transfer, subject to the nodal-plane ambiguity of the focal mechanisms and uncertainty in models of the secular stress conferred by fault slip at depth. Catalog analyses (SCSN and Harvard CMT) do exhibit stress triggering, but such tests are very sensitive to the rules and treatment of the catalog (Dave Jackson and Yan Kagan; Ruth Harris and Bob Simpson). New tools for dealing with nodal-plane ambiguity (Jeanne Hardebeck and Egill Hauksson), however, should permit better tests in the near future.

Although very large prehistoric earthquakes are tantalizing targets for investigation, it is going to be very tough to study stress transfer from the paleoseismic record because of imprecise fault slip distributions and earthquake dates (Dave Schwartz, Tom Rockwell). But knowledge of the timing and extent of the most recent prehistoric event is rapidly improving (for example, along the Landers, northern San Andreas and southern Hayward faults). This will enable estimates of the total stress state at the start of the historical catalogs and will be valuable for synthetic large-scale interaction models (John Rundle, Steve Ward).

Some stress triggering workshop participants took the optional sunset sail on the 65-ft sloop Zeus.
Above, left to right: Oona Scotti, Tom Rockwell, Roland Bürgmann
Below, left to right: Hugo Perfettini, Guy Ouillon, Mike Shulters, Dave Jackson

Photos: Ross Stein

Transient and Dynamic Coulomb Stress Change

Results incorporating viscoelastic deformation into stress calculations are promising (Shelly Kenner, Jian Lin, and Andy Freed) but have just begun to explore 3D effects (Fred Pollitz and Roland Burgmann; Jishu Deng). The stress transferred during the passage of the seismic waves is much larger than the static changes, particularly at large distances. Nevertheless, calculation of such transient stress changes is much more difficult (Debi Kilb and Paul Bodin), particularly when more realistic constitutive behavior is considered during the earthquake rupture process (Joan Gomberg).

Stress changes can be translated into earthquake probability changes with the help of the state/rate constitutive relations (S. Toda, R. Stein, Jim Dieterich, R. Harris, and B. Simpson). This has the potential to produce numbers that can be used by planners, emergency management people, and practitioners of seismic hazard analysis. Unlike the probabilities used today, such stress-based probabilities have the virtue that they are consistent with the occurrence aftershocks. What sets them apart is that they are highly time-dependent—even when the Poisson assumption is used.

What's Next?

More studies of earthquake sequences are needed to look closely at earthquake interaction; these are the building blocks for ideas about the role stress change plays in seismicity. The ideal is to probe large shocks falling within dense seismic, strong motion, and geodetic networks. This allows variable slip models to be developed, which in turn make stress calculations more accurate.

The prospects for such cases are best in California, Japan, New Zealand, and Hawaii. More effort is needed wringing results from earthquake catalogs (SCSN, Harvard CMT, JMA), using a set of testing rules on which everyone can agree, and SCEC is spearheading such an effort. Catalogs could also be used to validate probabilities based on stress change. But better secular stress models are essential to look at catalogs that span more than several decades, because the secular stress changes become as large as the earthquake stress changes. Such secular models are notoriously difficult to validate because different stressing models produce nearly identical surface displacements. Investigations of dynamic triggering are bound to reveal new insights about earthquake occurrence, as are 3D viscoelastic models and elastic models with spatially variable stiffness. Studies of the effect of super-low friction minerals, such as Brucite, and super-high pore-pressure fault zones could also prove enormously important.

Somewhere off in the future is an understanding of earthquakes that—while falling far short of prediction—would nevertheless supply a probabilistic forecast of where the next earthquakes, both large and small, are more likely to strike. At Carmel we could imagine such a future, although we only grappled with tools we hope will lead us there.

USGS News

New Northridge Summary Web Page

A new web page (www-socal.wr.usgs.gov/north) that summarizes the work of the U.S. Geological Survey following the 1994 Northridge earthquake is now online. Users can download data and maps showing many aspects of the earthquake, such as mainshock rupture, damage patterns, local site response effects, and landslide effects. Also available are various supporting data sets including a fault database, digital geologic maps, topographic data, and reference lists to Northridge publications. The site has photos from the earthquake and animations of the earthquake rupture and aftershock sequence.

RADIUS Supports Case Study Cities

Three regional advisory committees have been established to provide support for the RADIUS case study cities. The role of the committees is to visit the case study cities to provide technical advice and to raise public awareness of these activities. Committee members are from Asia, Latin America, Europe, the Middle East, and Africa. As a part of the RADIUS initiative, the Secretariat of the International Decade for Natural Disaster Reduction has begun the comparative study "Understanding Urban Seismic Risk around the World" for member cities. The study aims to understand factors contributing to the seismic risk of cities, underline the common earthquake risk problems in urban areas, and identify solutions and risk management practices that have been successful and can be duplicated. GeoHazards International (GHI) is responsible for this study. For more information, visit the RADIUS home page: WWW.GEOHAZ.ORG/RADIUS.

TALES FROM THE FRONT

by Susan Hough

Be Careful Out There—Some of the Hazards of Fieldwork

A lot of fieldwork stories are fun. They might not seem like fun at the time; more typically they seem exasperating or challenging or even a little painful. But you look back on these experiences later and smile, or even laugh. Yeah, they were *fun*.

As I embark on a regular column that it envisioned as a light feature, I feel impelled to start on a note that is no fun at all. The subject for my inaugural column is a grim occupational hazard of field scientists—automobile accidents.

I have to start this column on this note because in recent months we came all too close to losing two members of the earth science community to terrible accidents. About a year ago, the scientific community did lose an individual who was valued as a scientist, a husband, and a human being: Gene Shoemaker, killed in a freak accident on a remote road in Australia, in an accident that was nobody's fault but everybody's tragedy.

More recently, it was Lamont's Bill Menke and Caltech's Brian Wernicke who faced accidents that all too easily could have been fatal. Bill, driving with a field partner in white-out conditions in Iceland, went over a 900-ft cliff. Witnesses to the accident assumed it was not survivable; that it was survived by both occupants of the car is a shining testimony to the resilience of the human spirit. Bill has written a harrowing account of his experiences; you can find it at WWW.LDEO.COLUMBIA.EDU/USERS/MENKE/.

Artist: Jim Hensley

Brian's accident did not involve extreme driving conditions, but the fault (or mishap) of another driver who drifted into the wrong lane on a remote road in Nevada (and paid with her own life). Brian will also, thankfully, mend, but only after a long process of rehabilitation and subsequent surgery to repair damaged limbs. Brian's was the kind of accident that could happen to anyone, but is more likely to happen to someone who spends as many hours on the road—often on crummy roads—as does a field geologist.

Let's face it: every scientist who is involved with fieldwork does a lot of driving. Every one of us has probably driven in conditions that we would not have under normal circumstances, if not motivated by our passion for our science. When we get back from these expeditions, they might even be the stories on which we look back and laugh. The stories of driving in white-out conditions. Over roads barely passable. Long into the night. By ourselves. I have done such things myself.

To look back and laugh is the luxury of a survivor. As field scientists, we need to stop sometimes and consider the reality that, science or no science, we are still remarkably fragile biological beings who are no match for multi-ton machinery moving at highway speeds. We need to respect the limits imposed by biology and physics alike.

To honor the price paid by those of our colleagues who rolled the dice and got unlucky, let's be careful out there.

As a regular feature of the SCEC newsletter, "Tales from the Front" will discuss the human side of the fieldwork that provides "ground truth" for observational earth sciences. "Tales" will usually focus on the stories that bring tears of laughter. Occasionally, it will relay stories that evoke tears without the laughter. Some of these tales will be my own, but as many as possible will be those of colleagues willing to share. Everyone who's done fieldwork has a story. If you'd like to share yours, email me at HOUGH@GPS.CALTECH.EDU.

Interview with SCEC scientist . . .

Leonardo (Nano) Seeber

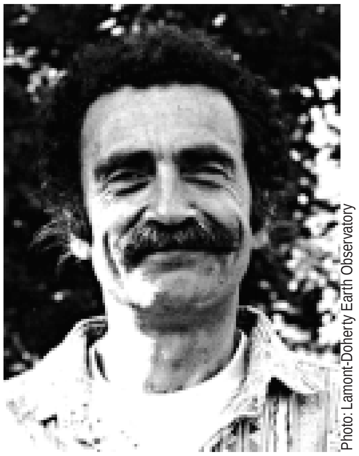


Photo: Lamont-Doherty Earth Observatory

SCEC Quarterly Newsletter includes interviews with SCEC scientists to highlight the interviewees' research projects and interests. We also discuss other projects and subjects to give a view of the scientist as participant in the larger scientific community and society in general. In this issue, SQN interviews SCEC director and multidisciplinary scientist Nano Seeber.

SQN—I understand that you were born in Florence, Italy, but that you have a link to the United States in your ancestry.

NS—An ancestor of mine was born in Vermont near the beginning of the 19th century, almost 200 years ago. He was artistically inclined and managed to get enough money from a benefactor to travel to Florence. He was successful enough as an artist that he stayed there.

Hiram Powers was his name, a rather famous sculptor in his time. He was one of the first American artists to be recognized in Europe. In that time, the first half of the nineteenth century, Americans were considered to be rough, uneducated, and certainly weren't expected to be represented in the European art world. Hiram Powers was one of the first to succeed in being recognized widely in Europe. The Smithsonian Institution owns quite a bit of Hiram Powers' work.

Americans were very keen to follow Powers' life. Newspapers and magazines kept sending interviewers to Florence to write articles about him and his work, so there is a fairly extensive record. In fact, an interesting story could be written based on the newspaper and magazine articles that John Armbruster came across while searching for records of pre-instrumental earthquakes.

Powers was in Italy at the same time that it was a popular second home for several of the best-known English Romantic poets. One of his acquaintances was Lord Byron. Our family still owns letters that he exchanged with Byron.

I have a connection to America that goes back even further than Hiram Powers. Either he or his wife had Native American ancestors. An uncle of mine researched the family back that far.

SQN—Then you were just another Italian kid growing up in Florence?

NS—Yes, but I'm old enough to have grown up during World War II, so the war overrode any other concerns. People were in disarray. It was a very complex time.

My mother might have still had Swiss citizenship. My father was Italian. In fact, he was called up to serve in the military. He was excused because of injuries he suffered while skiing. Later, he joined the resistance movement and fought against the fascists. For that, he was condemned to death, so our entire family had to hide in the mountains near Florence from both the Germans and the Italian government.

SQN—Did having a family history in art and being surrounded by art at home influence your life and work?

NS—Okay, a bit of psychological background: my mother was also an artist—a painter. In fact, her two brothers were also painters. But despite that heavy immersion in art, my mother convinced me that I was no good for art, but that I was good in science. She was interested in science but unable to do it herself. So I was driven in that direction simply because my mother said I was good at it. Eventually, I did my duty and learned a science.

SQN—Did that feel right to you?

NS—At first, no. I struggled. I think my inclination is really artistic. But once I was in it, I was determined to do well. By this time, I think I've reconciled those different parts of my background and instincts.

> If you don't need to, you shouldn't regiment things. The best way to prove that you can do something is to do it. The system ought to be more intelligent than it is.

SQN—Speaking of surrounding yourself with art, I understand that your wife is a dancer.

NS—Yes, she was a professor of dance at the State University of New York. She was also a lead dancer for many years, especially in the Limon Company, before leaving to join academia. Now she's back as an associate director of the company and reconstructing old dance pieces.

In dance, when a company wants to re-perform an older piece, the choreography has to be reconstructed—sometimes from very meager data, because it's not easy to record dance. It's a major job, and that's what she's been doing. She's definitely someone who knows the value of close attention to detail in achieving if not perfection, then at least the ultimate quality in her work.

She's very devoted to her profession. She's definitely an inspiration in the sense of taking her life's work seriously. She's also an inspiration in what art can do in terms of helping us understand things.

SQN—Does she participate in your scientific work?

NS—Yes, at times I do enjoy discussing things with her and getting her artistic reaction to the subject. She's so absorbed in what she does that she doesn't have much time to follow what I'm doing, and yet she does demand some openness from me. When we do succeed in digging into these things, it becomes very enjoyable for both of us.

SQN—Reconstructing old dance sounds similar to reconstructing old earthquakes from historical records.

NS—Yes, that's true. John Armbruster and I have been doing that for a while. It's a lot of fun. If you dig into it and think about it, eventually, you see it. The pieces fall into place, and I think you can do a remarkably good job of constraining old earthquakes and understanding what they are.

People were not aware of the physics of the event, but they were straightforward in describing what happened, giving honest reactions from which to reconstruct the earthquake. At least it's not biased. Well, I shouldn't say that. Sometimes it is biased, but that's part of the fun—to figure out what is biased and undo it.

For example, we tried to reconstruct what happened in the very important earthquake in 1886 in Charleston, South Carolina. We encountered a phenomenon we named the Charleston Effect. In those days the major concern was to attract settlers. Business relied on income from new settlers. So you certainly wouldn't want to scare prospective settlers by promulgating the idea that your spot was earthquake-prone.

Charleston itself became immediately famous around the world for having this earthquake. There was no way they could have pushed this earthquake away, so they decided they might not only admit the destruction but proclaim their need for help so that the city could get more money.

As a result, all the earthquakes anywhere nearby moved to Charleston. In fact, there were earthquakes that were quite far from Charleston, such as Columbia, South Carolina, which is about 150 km to the northwest. They were having aftershocks right there in Columbia, but they were calling them "Charleston earthquakes." And it took us some time to look into the data in detail to figure this out. The bias was definitely there in that case, but it was transparent.

SQN—I heard that you were a grape farmer in Italy for a while.

NS—Yes, for over three years. To explain what happened, I have to go back a few years. I was a graduate student here in New York in 1968-69. Things were pretty revolutionary in those days. I was very, very upset about the role of the U.S. in Vietnam. I felt I just couldn't participate, so I decided to go back to Italy.

My parents had bought a piece of land about 30 miles south of Rome, a beautiful spot. And so, I said, "Look, this piece of land needs tending; what if I do it?" They loved the idea. So my wife and I went to Italy to farm and build two houses—one for us and one for my parents.

We grew grapes on about 30 acres of land. We sold the grapes for wine. Also, we made a couple big barrels of wine for ourselves in the cellar.

It was a very beautiful time. I became strong physically and learned how to do those things. We did most of the work in the old-fashioned ways, which is very nice. But then, after three years of doing that, I realized that it was fun for a while, but I couldn't make a living out of it. Farming the old-fashioned way didn't pay—at least not in those days, before the concept of ecologically grown food had the appeal it does today.

In addition, I became restless. When Lamont-Doherty invited me back to be a seismologist again, I couldn't resist—particularly since it involved going to the Himalayas.

SQN—How is it that you came to the U.S. for college?

NS—My father was invited to work at the United Nations for two years on a project. We decided to move as a family—our parents and three siblings, a sister and a brother. I'm the oldest. I had just finished high school, so I applied to colleges in the U.S. and was accepted at Columbia. It was such a breath of fresh air from Italian education that when my dad went back to Italy, I was in no mood to go. Education here was very open. In the early 1960s, education

With Nano at the Coliseum

By Sue Hough

Fieldwork with Nano Seeber is always a bit of an adventure. But rather than regale you with sagas of lost rental car keys or seismometers dug in so deep they took me an hour to dig out, I will skip directly to a tale of work among hallowed ancient Roman monuments.

In the summer of 1990, an NSF-supported project teamed Nano, me, and colleagues from the Istituto Nazionale di Geofisica in Rome. Our project involved a characterization of site response around Rome, which led us to an effort to characterize both the site and structural response of the most famous of Roman structures, the Coliseum.

One of the first things I learned about the Coliseum is that it seems to be considerably more impressive to Americans than it is to the natives, who seem to view it as a traffic circle that is larger and dirtier than most.

After an initial reconnaisance, we determined that there were small cubbyholes in the upper walls that would be perfect for measuring the response of the upper levels, except that the bottoms of the cubbyholes were not flat enough for our seismometers. Nano and one of our ING colleagues disappeared into an office to discuss matters with the staff at the Coliseum.

After some minutes, Nano reappeared with a pick and chisel in hand. Dumbfounded, I inquired after the purpose of these instruments and was even more dumbfounded at the response: they had been given to us to level out the bottom of a cubbyhole so that we could make our measurements.

Back up several sets of stairs to the upper level, I stood at the bottom of a ladder that led maybe 30 feet up to a cubbyhole, listening with amazement to the "tink, tink, tink" of a chisel as Nano carved away bits of ancient rock.

This rock had withstood two millennia of ravages by humans and nature only to succumb in the end to this band of marauding scientists.

As a result, though, we got our data, and it revealed another of those worrisome correspondences between the site response of the Tiber Valley sediments and the dominant frequency of structural resonance. Both values were around 2 Hz; oddly, not very different from those estimated (without desecration) at New York's Shea Stadium and Flushing Meadows.

So if Rome is ever hit with an earthquake of appreciable size, the Coliseum might be in trouble. But at least for the time being, it's safe once again from the darker forces of science.

emphasized ability, not money or background. People were cutting through bureaucracies and getting to the substance of matters. I liked that. Culturally, Italy is old and kind of immobile with respect to the United States.

SQN—And what was your father's work with the U.N.?

NS—He had been involved in making short movies and other instructional material for farmers in the Italian Ministry of Agriculture. He was invited to do similar things for the United Nations. He came here with great enthusiasm, but I think his experience was not very positive. He felt the U.N. was bureaucratic and full of intrigue. And so he decided to go back.

I stayed at Columbia, eventually graduating with a degree in nuclear engineering.

SQN—And why seismology, then?

NS—I got more and more bored with engineering, particularly the applied part. So I decided to try to take some courses outside engineering, and I chanced upon a course in geophysics. I immediately loved it. It was general geophysics, but it included a lot of observation. The course included the basic information that went into the plate tectonic model that was beginning to take shape at the time.

I was also tired of studying. I wanted to do something. So I came to Lamont, where I was employed as a technical person. I stayed that way for a year but then started taking courses, eventually becoming a graduate student.

SQN—It sounds as though the artist in you was rebelling against the engineer.

NS—That's correct. My intuitive abilities were saying, "What about us?"

SQN—Were you aware of that at the time?

NS—No, I felt guilty, as you usually do at that age when things don't work. But I was very glad to see that something did interest me still.

SQN—What was the range of your interests at Lamont?

SQN—It sounds as though you're putting to use that varied background.

NS—It is definitely helping me at this stage in life, where I know my limits and abilities pretty well. I sense that my intuition covers quite a gamut of technical space. And even though I'm not familiar with the detail, I understand the basic operation in various fields so I can quickly catch up with what's going on.

> Many people toss aside small earthquakes as useless buzz. I think that in the future, the networks that are collecting data on small earthquakes are going to pay off generously. If earthquake prediction ever comes about in the sense it was originally envisioned, it'll be via these data, I'm convinced.

NS—I was very drawn by oceanography, both chemical and physical. I took many courses in it and did some research, and I enjoyed that. Then I felt that being on a ship wasn't exactly my ideal. When seismology offered me the possibility of taking instruments up into the mountains by myself, that seemed very appealing. I also liked very much the geology aspect of the problem of understanding the tectonics of active deformation of the earth.

Basically, I describe my approach as object-oriented rather than technique-oriented. I'm interested in understanding particular things or phenomena, and I will do anything to increase my understanding of these phenomena. I don't care what it is. If it's outside my field, I will tackle it. For that reason, I'm afraid I invade others' territory at times.

SQN—As I understand, you're a rare instance of a respected scientist who doesn't have a Ph.D.

NS—Well, I don't know about the first part. But it is true that I don't have a Ph.D. I was doing fine academically. I finished my thesis work and published a paper. But that was during the Vietnam era, and I felt outraged about the war. I just couldn't continue, so I left for Italy.

When I came back, it wasn't a complete decision right away. My initial view was that I was just going to do a job in Pakistan and then go back to farming. It didn't occur to me that I needed a Ph.D. for that. As time went on and I got more and more involved in seismology and geophysics, people started pushing me into doing the Ph.D., and I balked at it. It slowly became a point about which I didn't want to bend. I said, in effect, "If you want me, this is the way I am. If you don't want me—if you're going to push this Ph.D.—then I'll go somewhere else." Eventually the system bent. They promoted me even though I don't have a Ph.D.

SQN—Since you didn't bend on the Ph.D. issue, have there been any effects?

NS—No. I think that people realized that I was doing some interesting work—why disturb the situation? As the years went by, it became more and more irrelevant. I don't think it's an important issue either way. If you don't need to, you shouldn't regiment things. The best way to prove that you can do something is to do it. The system ought to be more intelligent than it is.

SQN—If you were advising a graduate student who is about to make a similar decision, what would you recommend?

NS—Well, I certainly wouldn't bet on my situation being replicated in the future—I'll put it that way. Lamont was young and more elastic than it is now. I think that's the trend in any system. As it grows, people feel the necessity of specifying everything.

SQN—As a member of the board of directors of SCEC, do you see regimentation happening there?

NS—We work hard at avoiding that. There are some key SCEC people who understand the danger of falling into the pattern of growing bureaucracy and regimentation. I would mention John McRaney as one of those people. He understands the danger and avoids it. And so I feel quite comfortable that we aren't going to fall into that trap.

SQN—The proposal to expand SCEC statewide is being written now. Is there a way of writing it to help prevent a stiffening bureaucracy?

NS—Well, I hope so. That's a much wider territory and much more diverse group of people. It is a big change. It's not clear exactly what it's going to bring about. But it's conceivable that the breadth of the institution will require more regimentation. I don't know, but there are certainly consequences that we'll have to address with regard to expansion.

SQN—What areas of research are you interested in now?

NS—Well, let's see. It's pretty wide, including the general areas of continental tectonics (intraplate, transitional, and boundary), tectonic evolution, and local mechanisms of microseismicity.

My work is mostly dealing with continents, and it goes through the range of the most active to the most inactive places. It involves fundamental mechanisms as well as the applications—that is, the hazards.

For the last few months, I've been working on the issue of intraplate hazard, the hazard in areas that have very low rates of deformation, such as the eastern U.S. Right now I'm studying the surprising number of triggered earthquakes in central India. By "triggered," I mean triggered by human activities.

I'm trying to understand why we have so many triggered earthquakes. Actually, I was trying to understand why some scientists think there aren't very many. I realized that the reason is that there are a relatively small number of such earthquakes in California, the most studied area.

Once you think about the physics, you can understand why that's true. First, I proceeded to write up an explanation based on the physics. And then, the next task was to understand implications regarding hazards. And I came to the conclusion that if you want to do any kind of useful hazard mapping in these low-strain areas, you need to include the sources that are related to human activities because they're not secondary. They're just as important as the natural earthquakes.

SQN—What are examples of triggering activities?

NS—Well, in the U.S., the last earthquake in Alabama, about magnitude 5, was right next to an oil field—triggering is strongly suspected.

When you pump fluid in or out of the ground, you change several things geologically. You change pore pressure inside the earth. Sometimes, to extract the oil, you pump another fluid (usually water or gas) into an injection well to push out the oil from an extraction well. That's moving a lot of fluid through rocks.

All this changes the stress. It turns out that you don't have to change the stress very much to trigger an earthquake in tectonically stable areas.

We studied an earthquake in Pennsylvania in 1994—it was one day before the Northridge earthquake. Few know about this earthquake in Pennsylvania, but it was big enough to do substantial damage. It turns out that a quarry triggered the earthquake.

When we calculated the stress involved, it was only 1 bar—a very small stress change relative to the stress level expected at failure. When you consider that in California, small earthquakes can be triggered by 0.1 bar stress change, then you should not be surprised that 1 bar can trigger an earthquake in the middle of a continent. Independent work has shown that stress is very high, even though strain rate is very low in tectonically stable areas.

In areas where strain rate is low, natural seismicity is going to be low. But if the environment is high-strung, anything you do that can change the stresses at the 1-bar level can trigger an earthquake. The more I look around, the more examples I find.

SQN—When you say a quarry triggered it, do you mean by blasting?

NS—No, it was the unloading. Actually, it's more

With Nano at Tianamen Square

By John Armbruster

In May of 1989, Nano and I went to Beijing for a month of work with Chinese seismologists. With the visit of Gorbachev, students began demonstrating at Tianamen Square, first as hunger strikers then using the white statue of the Goddess of Democracy as a focal point.

In the evenings, Nano and I would bicycle to the square to see what was going on. Many of the students there could speak enough English to tell us what their purpose was and to ask us questions. "Do people in the U.S. know what's happening here?" "What do Americans think about this?"

Nano's wife was in China at the same time, working at a school of dance at Guangzhou. I met her train when she arrived in Beijing to join us. She explained that student demonstrators had stopped and boarded the train, in effect commandeering it to ride to the demonstrations.

I watched as the groups of students formed, representing their universities. They raised banners, put on headbands with slogans, and marched, singing, to the square.

In our hotel at night, we listened to the BBC or the Voice of America on short-wave radio. Through the next day people would tell us what had happened locally and what the local media were saying, and we would tell them what we had heard. Then we would all try to sort out what was true.

Everyone was caught up in the excitement. Away from the square were roadblocks set up by local residents (Nano or I would sit in the front seat to ensure a quick wave-through). On visits to shopping areas, I often saw someone standing on an improvised podium speaking to a crowd that filled the street. The younger people were most active in participating. The older ones (the ones who had been through the Cultural Revolution) held back.

Nano and I spoke with students at the square several times. On one occasion, a man with a camera asked to take our photo. A minute later, when I turned back, he was gone. I realized that he was probably with the police or army, photographing any foreigner in the square.

Nano, his wife, and I left China on a Friday morning. The first reports of people being killed were that night. The major invasion of the square by the army was the next day. The white goddess was destroyed. Even in scientific fieldwork, it's not just science that happens.

complicated than that. The tectonic environment in Pennsylvania is technically known as a stable continental region. These regions are mostly in compression. When you move weight from the top, you increase the differential stress. But the next stage or complication is that removing material from a quarry usually means digging below water table, forcing the need to pump water out of the area in addition to removing the rock.

Pumping the water out means decreasing the pore pressure. On the one hand, you increase the differential stress. On the other hand, you decrease the pore pressure. You might have no seismicity up to the point when you decide that you're done with the quarry, move out, and stop the pumps. The water rises quickly in the quarry, and—wham—you have an earthquake because the pore pressure rises and weakens the fault. That's exactly what happened in this case. We can see it by the timing of the seismicity: a few months after the pumps are shut off, seismicity starts. In Pennsylvania, the seismicity started in April and the pumps were shut off in December of the previous year.

In that case, the seismicity started at a low level, but it built to this damaging M 4.7. In California a 4.7 usually won't do damage. But this was between zero and 2 km deep. Very shallow earthquakes are another characteristic peculiar to stable continental regions, which negatively affects the hazard in stable regions relative to California.

So that's a double whammer. Number one—when you perturb the stress, you're more likely to trigger an earthquake because the stress is close to failure and the rock is strong near the surface. Number two—when an earthquake is triggered, it's more likely to cause damage because it's close to the surface.

SQN—Has this work led to changes in regulations or practices?

NS—Not yet, but we will be producing a map for India—actually, for the state of Maharashtra, which contains Bombay. We're planning to work with the Geological Survey of India in making this hazard map. The map will include reservoirs, which in the case of Maharashtra are the main cause of triggered earthquakes. I think this will be a first.

I expect this issue of triggered seismicity to become more and more important in terms of hazard mapping. We have to develop a new technique to do hazard maps so that these sources can be included. The physics and the observations have come of age. I think that we can make a strong case that it just can't be ignored.

In India, there was an earthquake in 1993 that killed 8,000 people. It was a major event in the world press, which was full of news of this earthquake for over a week. It turns out that there's a reservoir next to this earthquake, and it was a difficult issue because in India, the population relies heavily on the irrigation system. To proclaim that it was a dam or reservoir that could have triggered the killer earthquake wasn't easy. It's still not easy. But I think that the evidence is mounting that the reservoir and the earthquake could be related. It's hard to prove it, though.

SQN—I understand that you've also worked on earthquake-triggered earthquakes.

NS—Right. We got very intriguing results from what we have done on that, primarily in southern California. Our main success there was to be able to invert for the rupture of the Landers earthquake using the far-field seismicity. By that I mean not the near-field aftershocks, but the seismicity from 7.5 km from the rupture to about 100 km.

> I'm confident that we know how to read seismicity and changes in the seismic regime that relate to stress changes. Therefore, we have a tool for monitoring the mechanical state of the crust.

We used the changes that occurred in the seismicity—not just the locations and magnitudes but focal mechanisms. Earthquakes' seismicity is displayed as seven-dimensional objects—locations are three dimensions; strike, dip, and rake are another three; and time makes seven.

We considered changes in seismicity represented like that and inverted the data for the slip distribution. We came up with a slip distribution that was very similar to what other people have found by looking directly at the earthquake.

I'm really confident that we know how to read the seismicity and how to read changes in the seismic regime that relate to stress changes. Therefore, we have a tool for monitoring the mechanical state of the crust.

As soon as I finish my current intraplate work, I'm going back to earthquake-triggering earthquakes in California because I think it has tremendous potential in helping us understand the mechanical evolution in the crust at a very detailed scale.

What I described is the latest product from those high-resolution earthquake data in California. A lot of work went into generating those data. We started by relocating these events and branding them with a level of accuracy, therefore optimizing the data in terms of reliability. Then we displayed the data so that we could look at them in three dimensions.

Now we have something like 35,000 earthquakes represented in the structural model. Just as a geologist would go around and map faults in terms of outcrops, I have gone around and mapped faults in terms of earthquakes. Considering together the spatial distribution of hypocenters and nodal planes, I interpret the plane that ruptured. When I display a large number of small earthquakes in 3D, the earthquakes often outline the faults and the interpretation is straightforward.

I think that this is the way to go in terms of using these data for structural interpretation. Once you've done that, the next stage is to invert these data in terms of stresses or stress changes because they don't represent much strain. (Most of the earthquakes are very small earthquakes.) You're not going to learn about the strain, which is primarily elastic; you are learning a great deal, I think, about change in stress.

It's a simple concept. Moments of large earthquakes are huge compared to the small earthquakes. The small earthquakes represent nothing in terms of hazard. Neither do they represent much in terms of strain. They're just a little noise on top of these huge events. Most of the plate's motion is accounted for by the huge earthquakes.

Many people toss aside the small earthquakes as useless buzz, and some people think that it's a waste of money to monitor them. I think that in the future, the networks that have been collecting data on small earthquakes are going to pay off very generously. People are going to realize that these small events are really important. If earthquake prediction ever comes about in the sense that it was originally envisioned, it'll be via these data, I'm convinced.

SQN—Because . . .?

NS—Because: (A) they're very sensitive to changes—and we're just beginning to figure that out; I think we can get much more sensitivity once we understand how to do it; and (B) because their sensitivity is right there where the big earthquakes nucleate. There's no other way as effective as that to know what's happening 15 km below the surface.

If you pose the right question, you're three quarters of the way there. The trick is going to be to find out what you're looking for, and then the earthquakes can be maneuvered around to tell you—to give you the information.

SQN—Are there differences in the human-triggered versus earthquake-triggered?

NS—I don't think so. The specifics of the field are different. The human triggers are very localized and mostly at or near the surface, but the theory should be very similar. In both cases, you are looking at Coulomb stress changes.

The other big difference is the preexisting condition. The stable continental regions have fundamental differences compared with California-type regions. There are several orders of magnitude difference in the strain rate. That's the number one difference.

In addition, in California the very strong shallow crust is not known to carry much elastic energy. I suspect also that the stress level is closer to failure, on average, in stable continental regions than it is in California. This sounds nonsensical, but I think there are a number of reasons why low strain and high stress can coexist in stable regions.

SQN—It sounds as though there's a lot of cross-pollination between the two types of studies.

NS—Certainly, at least in terms of the fundamental aspects. The data that we're dealing with are completely different. In the case of intraplate, we have little data and certainly not the thousands of focal mechanisms that we have in southern California.

Another thing that's very important in intraplate regions is the evidence of the faulting. California has features like the San Andreas fault, with gigantic slip rates and displacements. The intraplate crust has very subtle faults. The tectonic environment produces surface ruptures, but paleoseismic studies generally show only a few meters of displacement accumulated on faults over long geologic time with stable tectonics.

These faults are probably ubiquitous but very low, very subtle, and very slow. That's completely upside-down from California. It looks like the strain-softening phenomenon that regulates tectonics at plate boundaries is not operative for some reason in tectonically stable regions.

SQN—Your areas of investigation vary widely—China, the eastern U.S., India, Pakistan, Italy. Does the type of research vary as much?

NS—It varies quite a bit, actually. In the most recent, the work in the Himalayas, there was an experiment where I started primarily as a seismologist and ended up primarily as a geologist.

The issue is this mountain—Nanga Parbat in northern Pakistan—that's rising very rapidly. It's also an oddball in the structural pattern along the Himalayan front, which is remarkably uniform over 2,500 km. This mountain sticks out as odd in several respects. The task was to figure out why. We carried 60 instruments onto this mountain. At tremendous effort, we succeeded in operating these instruments around this mountain for six months in 1996.

During this process, I started looking at the geology, and I realized that Quaternary features carried some very critical information. So I went back and spent a month getting data, mainly on structures in Quaternary sediments. I was working by myself, and I probably have never been more productive in my life.

I succeeded in getting data to support the hypothesis that this mountain is responding in a major way to gravitational stresses controlled by topography. The question was how erosion, therefore topography, controls tectonics. To make a long story short, I formulated a simple hypothesis on how topography was affecting tectonics, and I predicted (fortunately, somebody was there to witness this prediction) certain faults to be there and for them to move in a certain way. Then I found them and mapped them.

I got a personal satisfaction out of that. Now I'm very keen on going back and continuing this work because I think that it's one of the best laboratories to study this interaction between erosional control of topography and tectonics.

SQN—Could you explain the mechanism a little more?

NS— Nanga Parbat is rising at possibly a centimeter a year. The Indus River is next to the mountain and acts like a chainsaw that forces topography on the river to be about a kilometer high, no matter what. The river carries away the uplift. It's a very energetic river. Right next to it is Nanga Parbat, over 8 km plus high. So you get 7 km of relief.

A 7-km-deep valley produces huge stresses, and the earth responds to these stresses by trying to fill this hole from below. And the river keeps eroding it away. It's like two very determined people working against each other.

A major thrust fault surfacing along the valley keeps pouring material into the valley, and the river keeps taking it away. So tectonics is "hyperactive" along the river. You get tectonics controlled by the river. It's a unique example, because of the combination of very high topography and very high erosion rate.

SQN—Is that unique?

NS—I've heard that there is a similar situation on the

> I expect the issue of triggered seismicity to become more and more important in terms of hazard mapping. The physics and the observations have come of age. We have to develop a new techniques to include these sources.

other end of the Himalayas where the Brahmaputra River comes through. But I'm sure that on a smaller scale, you can find similar places.

SQN—If big changes in topology affect seismicity or tectonics, then what about glaciers?

NS—That's a very interesting issue. For example, under the continents that are covered by ice sheets, there's no seismicity. Greenland and Antarctica are pretty much devoid of seismicity. That's been ascribed to the glaciers. If you remove those glaciers all of a sudden, you would expect a lot of earthquakes.

In fact, in Scandinavia, where a very thick ice sheet was covering the land only 10,000-12,000 years ago, you see long fault scarps as much as 10 m high and 100 km long that postdate the glaciers. They are probably the geologic evidence of a burst of large earthquakes that followed deglaciation. That's the effect of glaciers on the continental scale.

Glaciers are also extremely effective erosional machines, so earthquakes may respond to that. If 1 bar can trigger an earthquake, a glacier can easily do that and much more either by its own motion, by pushing rocks out of the way, by damming water and creating a lake—in all kinds of ways.

SQN—Does global warming come into play?

NS—That's right. Right now, John Armbruster and I are working on some data that suggest that seismicity in southern California may be controlled in small respect by rain. We have a method of leveraging the small signal related to rain out of the data. It's still preliminary, but there's something there, I think. It's a side issue, but we can't resist the temptation of looking at it.

SQN—What's your most current SCEC work?

NS—Some research I'm doing for SCEC with Chris Sorlien is important, I think. As you know, there are methodologies to model structures related to faults—fault bend folds and fault-propagation folds are typical folding models where the fold is related to fault slip.

We sense that those models, although they're appealing, are too restrictive. There might be completely different ways that folds can be associated with faults. We're looking, for example, at what would happen if you reactivate a normal fault that is listric (curved, without a sharp angle).

Not far back in geologic time (I think mid to late Miocene) there was still major extension going on in a wide area of southern California. So there are a lot of extensional faults around. Another notion that's pretty accepted is that faults remain weak, and when you change the stress, they may still be used for accommodating strain in some other direction from what they were originally designed for. So that's what we think is happening in a lot of faults in southern California.

Normal faults, everybody seems to agree, tend to be listric, and do not normally have a flat, ramp-type geometry. So if you turn the stress around on a normal fault and make it horizontal compression instead of horizontal extension, then you may take one of these listric faults and reactivate it backwards. We think that we see evidence of that in several instances, particularly in the case of a major fault that is associated with the fold that controls the Channel Islands.

And that's an area that has plenty of data and has plenty of models being proposed. We propose a new model, basically a listric-thrust model, to account for that deformation and for the folding. If you range through a variety of models as wide as we think you should, then your results can be quite different—in terms of strain or slip rates and, therefore, earthquake rates—from what you get, say, if you accept only a ramp-flat fault model.

> To prove that the reservoir may have triggered the killer earthquake is not easy. But I think the evidence is mounting that the reservoir and the earthquake could be related.

SQN—You've done some work related to sediment nonlinearity. Is there any relationship to your other work?

NS—It really doesn't relate to the other work directly. The other work is about the mechanics of stress and strain at seismogenic depths, where big earthquakes are nucleated—in other words, the sources of earthquakes. Sediment nonlinearity is problem of what happens when the seismic waves from these sources enter low-strength, low-velocity sediments or sedimentary rocks in a basin such as the Los Angeles basin.

That's a wave propagation problem. It's a very complicated problem, but it has gone forward tremendously in the last decade. People have the tools now to model these waves with good expectations of being realistic. And it turns out that the effect of these basins on the wave propagation and the wave amplification, which is what counts at the surface, is rather drastic. You can have large amplifications and large distortion of the waves so that the motion is going to be very concentrated at particular frequencies and in particular spots.

A unusual wrinkle on the wave propagation issue is that, in the calculations and observations, the areas where the sediments are particularly weak, a substantial portion of the energy may be absorbed. Therefore, the sediment is not behaving as an elastic body any more. The modeling has to include this factor—that a lot of the waves' energy is dissipated. That's a plus in terms of hazard because attenuation in sediment may contribute to decreasing the amplitude of the waves, particularly at high frequencies. But we have to be very certain of the data and models before getting specific about those local responses.

> I suspect that the stress level is closer to failure, on average, in stable continental regions than it is in California. This sounds nonsensical, but I think there are a number of reasons why low strain and high stress can coexist in stable regions.

The tools are still in the development stage, but the observations are coming. The basic understanding is there to a substantial degree.

I started working on that in Italy when the issue was beginning to receive attention. But you have to make choices, and I have opted to concentrate on earthquake sources and tectonics.

SQN—I also understand that you have been involved in some interesting outreach and education projects.

NS—I worked on a project called EarthView Explorer, directed toward creating a tool that can be used mostly in high school and middle school to bring data and exercises that will be fun and realistic to the students. I had a major role in planning it, but I moved to the backseat when things started rolling.

Another project I did was very fascinating. I was asked to contribute ideas for a major permanent exhibit at the American Museum of Natural History in New York City. The exhibit, called Hall of the Earth, is under construction. The museum wanted ideas about how to use data to demonstrate basic earth science principles. I found that quite exciting. It's surprising how many things you can do once you understand the physics and you apply some imagination.

They didn't particularly care whether the proposals involved difficult or expensive technical problems. The museum just wanted imaginative ideas to make the viewers understand the functioning of the Earth via current phenomena. For example, a real-time plot of solid-earth tide as recorded at the museum combined with a real-time image of the Earth, the Moon, and the Sun, showing how their relative positions relate to the tide.

Interviewer: Ed Hensley

Technology for Learning Initiative

SCEC Teams with L.A. County to Improve Earth Science Teaching

By Sara Tekula, SCEC Outreach Specialist

Over the years, it has come to our attention at SCEC that there are far too few resources and opportunities for students and teachers in the urban areas of Los Angeles County. The SCEC Outreach Team has felt the need to impact the diverse student population in Los Angeles County, housing over 1.6 million students, but didn't know where to begin such an endeavor. Now, the chance to create a significant and lasting impact has arisen through a project aimed at providing student and teacher access to technology.

The Technology for Learning (TFL) project is a public-private collaborative with the mission of making Los Angeles County a national leader in educational technology. Headed by Executive Director James Lanich, TFL has divided Los Angeles County into 14 regional consortia to collaborate, leverage resources, share expertise, and plan implementation. Five "Communities of Excellence" have been organized throughout the county to examine the role of "technology in learning" in the core subject areas. These communities of educators, parents, students, and business/ industry members are developing and sharing lessons and strategies for incorporating technology into the classroom. The successful strategies will then be implemented throughout the county.

The South East Educational Technology Consortium (SEETC) covers a student population of about 200,000 and makes up 13 percent of Los Angeles County's total student body. SEETC is also a Community of Excellence, focusing on earth and space science. Jill Andrews, SCEC outreach director, and I met with Rich Alvidrez, who manages the Jet Propulsion Laboratory's public education program. JPL had partnered with SEETC's Community of Excellence, and Rich was on board to help incorporate technology into their science curricula.

Around the same time, SCEC had been assessing the DESC (Development of Earth Science Curricula) Online educational products and determining the best ways to use those tools in the educational community. SEETC had identified desirable "learning outcomes" for SEETC, based on a report of common difficulties among the county's science teachers. The teachers reported problems teaching plate tectonics and other earthquake-related topics. Needless to say, SCEC's Outreach Team joined on as a partner with SEETC.

I have been working with a group of teachers and curriculum developers to design a framework to implement the county's earth science courses. One way we're doing this is by professional development. I believe that if teachers have difficulty teaching a topic, it is most likely because of their own difficulty understanding the topic.

The current DESC Online education modules (see related story in "SCEC News Briefs") are aimed at community college students, which is a perfect level to help enhance the knowledge of middle-school earth science teachers, most of whom are trained at community colleges. How this in-service training will take place is not yet certain, but it should happen at the close of the fall semester.

Another way to implement the courses is to update the way they are taught. Along with teachers Paul Killian, Eric Johnson, Barbara Keenoy, and Alma Allen, I am designing a storyline for an earth science unit in a middle-school classroom. We'll take a historical approach, telling the story of science instead of an outline of loose facts. Rather than memorization and multiple-guess testing styles, students will learn to think like scientists who first imagined the theory of plate tectonics. Instead of matching proper definitions in tests, students will be asked to retell the story of how the theory evolved.

Portions of the education modules and other online SCEC maps and databases, have been referenced as activities for this curriculum unit. When the DESC Online modules have been modified for the middle-school level, the teachers who were trained on the modules will have a familiar teaching tool from which to pull activities, lessons, interactive real-time maps, GPS and seismic data, and information about local faults. The middle-school modules will mirror the storyline framework developed with SEETC.

The unit that my group has developed will be beta-tested at schools in the SEETC region, and if approved, will be furnished throughout the county. To find out more about L.A. County Office of Education's Technology for Learning initiative, visit its website: www.lacoe.edu/tfl/tfl_home.html.

Intern Colloquium

Undergraduate Interns Get to Know Each Other and the Ropes

Photos: Mark Benthien

On August 13, 14 and 15, the SCEC Undergraduate Summer Internship recipients attended the 1998 Intern Colloquium. This was their opportunity to meet fellow interns as well as many SCEC scientists, tour SCEC facilities, and visit research sites.

The 1998 Summer Internship Program is hosting eight students from five schools. See the last issue (4.1) of this newsletter for a description of each student's project and goals.

Day one was spent at USC. The day began with presentations by SCEC scientists and administrators, detailing SCEC's accomplishments, plans, and current research projects. Tom Henyey, Jill Andrews, Kim Olsen, Monica Kohler, Yehuda Ben-Zion, and Zheng-kang Shen each gave a presentation. The afternoon was spent with the interns sharing their projects with each other.

Day two was the first day of a tour of SCEC facilities and southern California faults. The first stop was at Caltech to learn about the Southern California Seismic Network and the Media Center. Also at Caltech, Lisa Sarma showed the group her project, which involves placing vibration-inducing motors on top of the nine-story Millikan Library so that seismometers throughout the San Gabriel Valley can detect the oscillations. The interns next visited Loma Alta Park, the site of a recent trench across the Sierra Madre fault by James Dolan. The interns then met with Andrea Donnellan at JPL. She demonstrated how GPS technology is used to measure earth movement throughout southern California. At JPL, the interns also viewed an exposure of the Sierra Madre fault. The group then headed east to Dolan's newly opened trench on the Raymond fault. Dolan also led the group to the site of a trench across the Cucamonga fault. The last stop was Sally McGill's trench on the San Andreas, which is the project of intern Safaa Dergham. The night was spent at Kerry Sieh's home near Lake Arrowhead.

Day three began with a tour along the San Andreas fault toward Palmdale led by Mark Benthien. The interns visited the "Earthquake Trees" near Wrightwood and Sieh's groundbreaking trench site at Pallett Creek. Next they stopped at the Hwy 14 roadcut exposure of the San Andreas being mapped by Lowell Kessel. The final stop of the trip was at the Van Norman Dam in San Fernando, Intern Javier Santillan's project site, where Fabian Bonilla and Aaron Martin demonstrated borehole seismology and seismic instrumentation.

OUTREACH BY THE SCEC COMMUNITY by Mark Benthien

We're All on the SCEC Outreach Team

Many scientists, students, and others in the SCEC community are involved with education and knowledge transfer activities that are not coordinated by Jill, Sara, and me, but are nonetheless outreach activities. SCEC's outreach efforts have been traditionally described as the activities organized by SCEC's Outreach Team. We'd like to expand the scope of that definition.

We'd like to find out more about your own formal or informal "outreach" efforts; by highlighting them here and on the Web, we hope to encourage others to participate in their own ways. We feel that the efforts and contributions of everyone in SCEC should be recognized and acknowledged as an integral part of SCEC's outreach effort.

We have been surveying the SCEC community for such activities. As we find out about them, we will highlight them both on the SCEC web site and here in the newsletter. Please take a moment to email me (BENTHIEN@USC.EDU) a list of outreach you have done over the past year and what you plan for the rest of 1998. Please include any comments on how your outreach efforts have benefited you and your science.

Examples of education activities include giving talks about your work, describing your research to people who live near your project sites, leading field trips for students or teachers, being a mentor for students,

Artist: Jim Hensley

and teaching general undergraduate earthquake courses.

Examples of knowledge transfer activities include acting as a consultant for government agencies or private companies, attending workshops and scientific meetings where you present your research, developing online databases, being available to the media, and leading field trips.

The following are highlights from initial responses to the survey:

Luciana Astiz (UC San Diego)

- General talk on earthquakes to first graders at Spreckels Elementary
- Talk on California earthquakes, their connections to California Missions, and seismic hazard to third and fourth grade students
- General talk on plate tectonics to seventh and eighth graders
- Review of the SCEC web seismic module 1
- Present relocation work on the 1986 Oceanside earthquake at the 1997 IASPEI meeting in Thessaloniki, Greece

Erik Bender (Orange Coast College)

- Teaching an undergraduate courses entitled "Earthquakes" and "General Geology"
- Using the CUBE system and associated exercises extensively
- Setting up, with help from the USC geophysics personnel, a local seismic network with eight sensors and seismographs available for public viewing in our Applied Sciences Building
- Leading a number of field trips for the local CERT (community emergency response teams) in Huntington Beach to local faults to examine a number of potential seismic hazard areas

Steve Day (San Diego State University)

- In the past year, teaching a course called "Natural Disasters" to about 100 undergraduate nonscience students
- We (the geology department staff) created a public exhibit on earthquakes, centered on a CUBE system display, in the SDSU geology department

Gary Fuis (U.S.G.S. Menlo Park)

- Press release—"Three years after Northridge, scientists have a better 'picture' of what is beneath part of the Los Angeles basin" (with P. Jorgenson, R. Clayton, and T. Henyey), 1/16/97.
- Media interviews—on LARSE (Good Morning America, KCBS and other radio stations; Los Angeles Times, various other newspapers)and on the Northridge earthquake (TV)
- Mentoring—N. Magnutsky, Palo Alto High School ("Amplitudes of LARSE Explosions as a Function of Distance, Shot Size, and Geology")
- Video tapes—*The Los Angeles Region Seismic Experiment* (by SCEC and USGS); *Imaging the Earth beneath Los Angeles: The Los Angeles Region Seismic Experiment* (by SCEC, CSU Dominguez Hills, and USGS)

JPL (Maggi Glasscoe, Andrea Donnellan, Mark Smith, Anne Mikolajcik, Mike Watkins, Frank Webb, Greg Lyzenga, Ken Hurst, Michael Heflin)

- Educational module on the use of GPS in earthquake studies (SCIGN.JPL.NASA.GOV/LEARN).
- Recruiting schools to test the GPS module.
- Seminars, guest lectures, and speeches at several local schools and to insurance companies
- Field trip for the SCEC interns
- Seeking prospective site hosts for SCIGN
- Press interview concerning SCIGN and other geodetic research
- Volunteering at local high school and helping with physics lab
- Working on web pages and brochures about the use of GPS in earthquake research.
- Time series Web site, mirrored by a school in New York which uses the GPS data in math and science activities.
- Helping with JPL open house activities, including a booth explaining research.
- Planning for outreach for the proposed California Earthquake Research Center.

Mark Legg (ACTA, Inc.)

- Santa Catalina Island field trip (GSA Cordilleran with Dan Francis)
- Coastal Erosion field trip, Carlsbad stop (with Ben Benumof, Gerry Kuhn)
- WHOI Alvin dives with VIPs at San Clemente fault scarp
- Treasurer of L.A. Basin Geological Society (many SCEC speakers)
- Assist and consult mortgage bankers and lenders in assessing earthquake loss potential
- Assist students in offshore fault studies, CSU Long Beach and SDSU

continued on page 27 . . .

SCEC Workshop Report

Physics of Earthquakes: State of Our Knowledge

By Charlie Sammis

A SCEC workshop on the physics governing the behavior of earthquakes and faults was held at the Snowbird Conference Center in Utah from June 21 through June 23. Convened by Yehuda Ben-Zion and Charles Sammis, the objective was to assess the current state of understanding of earthquake processes ranging from nucleation of events to propagation and arrest of ruptures, spatio-temporal seismicity patterns, interactions between faults, and evolution of geometrical and other properties of fault systems.

There are many approaches to such problems including continuum mechanics, statistical physics, laboratory experiments, and field observations. By bringing together experts in the various approaches, the hope was to compare results and identify key problems for future research that could be incorporated into the proposal for the new California Earthquake Research Center (CERC). A total of 53 scientists from within and outside the SCEC community, representing universities, the national laboratories, and government participated in the workshop.

The Sunday session began with a welcome from SCEC Director Tom Henyey, who reviewed the CERC preproposal that has been approved to be followed by submission of a full proposal, due on September 4. He pointed out that CERC would place more emphasis on the physics of earthquakes. Henyey charged the workshop to articulate what we now know, what we would like to know, and approaches to get there including key required observations. The remainder of Sunday was devoted to one-hour overview presentations of the status of the various approaches now used to study the physics of earthquakes.

Yehuda Ben-Zion began with brief outlines of lab studies, fracture mechanics, damage rheology, granular mechanics, and statistical physics approaches. He commented that while a unified framework for earthquake physics does not exist, a good common reference might be the equations of motion for a continuum solid. These equations are scale-independent, suggesting that deformation processes should produce self-similar patterns manifested in power-law statistics.

Such patterns are indeed abundant in earthquake phenomenology. However, length scales associated with rheology, existing structures, etc. can produce important deviations from self-similarity. Ben-Zion gave two examples. The first is a transition from stable creep to dynamic instability at a nucleation size whose dimensions depend on frictional and elastic parameters. This transition, defining a minimum earthquake size, fueled hopes to observe the precursory deformation associated with the nucleation process. However, high resolution geodetic measurements and the existence of M – 1 events on the SAF indicate that even on major faults, the nucleation zone is too small to produce detectable surface signals. The second, and larger, example of a transition-breaking self-similarity stems from the scaling of stress concentration in continuum solids with rupture dimension, which can produce a critical event size terminating the power-law regime of frequency-size earthquake statistics.

> Many foreshocks that occur immediately before the mainshock actually reduce the Coulomb stress at the hypocenter, moving it further from failure.

Power Laws

Ben-Zion reviewed the suggestion that these may result from proximity of dynamic variables to critical points of phase transitions. He recalled that while classical critical points are associated with specific values of "tuning parameters," self-organize-criticality (SOC) involves stationary critical behavior for a wide range of parameters.

He noted that detailed experimental and theoretical works do not support the assertion that SOC describes earthquake dynamics. He also pointed out that early claims for generic dynamic complexity on a smooth homogeneous fault have not been supported by later studies and that recent results indicate that dynamic complexity, like criticality, occurs only for narrow ranges of tuning parameters. The identification of the tuning parameters (e.g., geometric disorder and dynamic weakening) and associated critical values are important subjects of continuing theoretical and observational research.

Moving to details of individual ruptures, Ben-Zion commented that a challenging front here is the proper understanding of energy partition at crack tip and the trajectory (including branching) of dynamic ruptures. Classical theory and recent lab experiments indicate a transition from smooth rupture to rough crack surfaces and branching at rupture speeds lower than those commonly inferred for earthquakes. This is compatible with the strongly disordered structures of immature fault systems, but not with the long, straight fault traces characterizing mature fault zones and the long, straight ruptures seen in such systems.

A possible explanation may stem from dynamic reduction of normal stress that accompanies slip on a material interface, which may trap ruptures in fault zones with well-developed interfaces. In such structures, the same mechanism produces self-healing ruptures with short rise times and a small amount of frictional heat. Other explanations for some of these phenomena include evolving fluid pressures and mechanics of granular media. Ben-Zion noted that progress in the above topics will require lab measurements of branching processes and friction at high slip velocity as well as accurate seismological observations of static and dynamic stress drops and rupture velocity and dimensions. The latter involves high-resolution velocity models especially for fault zone structures.

Continuum Mechanics

Jim Rice, who reviewed the status of continuum mechanics modeling of the earthquake process, gave the second talk. He pointed out that rigorous models for which a continuum limit exists are limited by the size of the earthquake nucleation zone that scales with the characteristic slip distance associated with frictional weakening and small time steps associated with rapid weakening of evolving fields. Models that incorporate nucleation zones based on the sub-millimeter slip weakening distances found in the lab are not yet practical.

He further pointed out that the broad distribution of event sizes observed in nature are not generic to continuum fault models but sometimes occur for certain ranges of model parameters and can be enhanced by tuning the velocity-weakening friction laws. However, we still lack a systematic understanding of these conditions. Further, event populations with power-law statistics are never seen in a continuum model with a single weakening mechanism but appear to be generic in inherently discrete models in which a continuum limit does not exist or was not obtained due to oversized cells.

On the other hand, broad event statistics can be produced using a continuum model that incorporates a pair of weakening mechanisms, one of which nucleates at small scales and produces a very small stress drop and one that nucleates at scales on the order of the crustal seismogenic depth and involves a nearly full stress drop. The reasons for this are not fully understood.

Other issues in continuum earthquake models raised by Rice involve:

- The extension of rate- and state-dependent friction to high slip velocities which operated during an earthquake
- The rupture of strongly heterogeneous faults that break through geometric complexities and fault networks
- The role of strong heterogeneity or dissimilarities of fault properties across a fault plane in producing a short-duration slip pulse and associated phenomena
- How one earthquake contributes to another through stress transfer and how this differs between mature highly slipped faults and immature little-slipped faults
- Studies of branching of dynamic rupture.

Finally, Rice raised three general questions:

1. Why is the stress level low (≤ 200 bars) along high-slip plate-bounding faults where the large earthquakes occur but high (consistent with lab friction) in the more stable crust where large earthquakes rarely occur?
2. Is the rheology at the base of the seismogenic zone controlled by hot frictional sliding on the fault plane, which satisfies rate- and state-dependent friction and exhibits velocity strengthening or by a high-temperature creep mechanism?
3. Does dilatancy or strong velocity strengthening stabilize shallow fault rupture?

The notion of a regular “recurrence interval” has also been rebuffed by the notable absence of the cyclic Parkfield earthquake, which is now more that 10 years overdue.

Statistical Physics Perspective

Daniel Fisher discussed the earthquake source from the perspective of statistical physics. He began by raising the question of whether the Gutenberg-Richter power law frequency-size relation is due to the distribution and geometry of faults and therefore reflects some aspect of the long-time geological history or whether it arises from the dynamics of failure on individual fault systems. He proposed to focus on individual fault systems because they are simpler and more easily modeled and to explore the roles of: long-range elasticity; dimension of the system; heterogeneities; stress waves; friction laws; and history.

The goal of a statistical physics approach is to understand the types of possible earthquake statistics and the “shapes” and dynamics of ruptures. Shapes of earthquakes, Fisher explained, deal with the question of whether the rupture is crack-like or pulse-like, whether it is connected or island-like, irregular, compact, or fractal. The shape of an earthquake determines how it scales—that is, how the slip, area, moment, and duration scale with effective diameter.

If a wide range of power law scaling exists, then “universal” explanations may exist. The hope is that these explanations are robust in the sense that they depend only on a few features such as dimension or range of forces and are independent of most detail. Equilibrium systems that involve stable phases and critical points are fairly well understood analytically, but nonequilibrium systems, to which earthquakes belong, are not—although there have been many computer simulations.

Fisher outlined a strategy to understand the origins and robustness of scaling relations in seismicity. Begin by writing the effective equations of motion (which may be statistical) that depend on length scale. Then use the renormalization group technique to study the system scale-by-scale to see how small-scale features affect large-scale ones. The strategy is to start with simple models or “caricatures” of the real system and then add features of the physics one at a time to see if a given feature is irrelevant in that it doesn’t affect the scaling laws or is relevant in that it changes the scaling laws (and the universality class) or even destroys scaling altogether. The goal is to find out what is important and what isn’t in understanding the observed scaling relations. He then gave several examples of this procedure, based on a model of a single fault system with heterogeneous properties.

Field Paleoseismicity Studies

Tom Rockwell reviewed field paleoseismicity studies focusing on the extensive work on trenching active faults in southern California to date prehistoric events. An exciting result to come from this work is the tendency for large events in a given region to cluster in time. In the eastern Mojave, all the trenched faults show a major event in the past 2,000 years, with another peak of activity between 4,500 and 6,500 years ago, another between 8,000 and 10,000 and a weak peak between 14,000 and 16,000 years ago. Similarly, the faults in the Salton trough show clustering of large events at approximately 1,200; 1,350; 1,500; 1,675; and 1,925 years before the present.

Greg Beroza presented seismic observations of the source process, including the imaging of heterogeneous slip and the Coulomb stress changes that foreshocks produce at the hypocenter of large events. He discussed the rather surprising result that many foreshocks, which occur immediately before the mainshock, actually reduce the Coulomb stress at the hypocenter moving it further from failure. Beroza showed observations of repeating microearthquakes and discussed their use for inferring time-dependent properties of faults. He also discussed the possibility that observed seismograms contain signatures of dynamic breakouts from earthquake nucleation zones that scale with the final event size.

Jim Dieterich discussed the laboratory contribution to our understanding of source physics. He reviewed basic rate- and state-dependent friction theory and recent direct experimental observation of asperities on transparent sliding surfaces that support the physical interpretation of rate and state parameters in terms of the density, size, and lifetime of surface asperities. He then went on to show how rate- and state-dependent friction theory can be used to calculate changes in the rate of regional seismicity following a stress change. In particular, he showed that rate and state friction theory can lead to Omori's observational law, in which the rate of aftershocks decreases as the inverse of the time since the mainshock.

Earthquake Prediction

In the final talk, Charlie Sammis discussed the prospects for earthquake prediction. He pointed out that although prediction was not a reputable pursuit in the early 1960s, the subsequent discoveries of plate tectonics and laboratory precursors have provided a physical basis that legitimizes prediction research. Plate tectonics tells where earthquakes are likely to occur, and why, and thus offers a "prediction" of location that is better than the base level null hypothesis of a random distribution in space. Recent calculations of the change in Coulomb stress associated with large events offers the promise of even better spatial predictions.

Temporal prediction has been more problematical. Physical precursors observed in the laboratory before the failure of a rock specimen have not been consistently observed in the field. Temporal predictions based on "recurrence intervals" seem ill-conceived based on the careful paleoseismic studies at Pallet Creek on the San Andreas, which find an average recurrence interval of 134 years, in rough agreement with that expected based on plate tectonic strain rates. But the intervals scatter widely about this average, ranging from 44 to 332 years. In fact, like the seismic patterns discussed by Rockwell in an earlier talk, large events on the Mojave section of the San Andreas seem to come in clusters of two or three events, separated by less than 100 years, with longer cluster intervals on the order of 200 to 300 years. The notion of a regular "recurrence interval" has also been rebuffed by the notable absence of the cyclic Parkfield earthquake, which is now more that 10 years overdue.

The observed lack of periodicity has led many to conclude that regional seismicity, like the weather, is chaotic and inherently unpredictable. Some have argued that the crust is in a continuous state of SOC, which implies that an earthquake at any time can cascade into a major event.

Sammis argued, as did Ben-Zion, that there is evidence that the crust is not in a state of continuous SOC, which includes recent documentation of regional "stress shadows" following large events and observation of the clustering of intermediate events before large earthquakes. He proposed that the largest earthquakes in a region perturb it away from the critical state and that methods of statistical physics can be used to monitor the return of the region toward criticality and the next large event.

He presented examples of the approach and retreat from the critical state in simple cellular automatons with loss or structural complexity and showed examples of the power-law increase in seismic energy release preceding large events. He concluded that statistical physics suggests new precursors to look for in the quest for temporal prediction.

The second day of the workshop was devoted to short presentations by participants and to group discussions. For the group discussions, it was decided to divide not by disciplinary groups but by problem area. Four groups were formed: tectonic framework, earthquake source processes, fault and stress evolution, and seismic hazard assessment. Each group was charged to identify key issues and to suggest promising approaches. On the final morning, the leader of each group presented a report to the workshop. These reports will provide material for the CERC proposal.

FEMA Launches National Project

The Federal Emergency Management Agency launched Project Impact: Building a Disaster-Resistant Community and invited 50 localities to become the initiative's first disaster-resistant communities. Project Impact is a national effort that aims to reduce the costs of disasters. The initiative challenges communities across the nation to build local partnerships, to assess vulnerabilities to natural hazards, and to implement actions that protect families, businesses, and communities by preparing for and reducing the damaging effects of natural disasters.

The first round of communities will form a peer-to-peer network of American communities building partnerships and taking actions to prepare for natural disasters. In each community, a local partnership of government leaders, representatives of the business sector, and individuals will provide funding, in-kind services, technical support, and labor to undertake disaster-resistant activities. In addition, FEMA will provide technical support and funds to states to provide administrative support to the initiative.

The national launch of Project Impact follows the successful demonstration of the program in seven pilot communities nationwide. The seven pilot sites were selected for their geographic and demographic diversity and include large cities, rural areas, coastal communities, and riverine communities. In each pilot community, local partners have undertaken actions to protect themselves against disasters where they live and work. A list of the 50 communities invited to become part of this project is on the FEMA web site: WWW.FEMA.GOV.

SCEC News Briefs • SCEC News Briefs

SCEC Outreach Staff

Career Talk at California Science Center

On July 1, SCEC outreach specialists Mark Benthien and Sara Tekula gave a "Careers in Science" presentation for high school students at the new California Science Center's K-12 Summer Science Camp program.

Mark, who has a degree in geophysics, spoke on behalf of the careers in science that require a science background. He mentioned that people who study earth science are not limited to teaching or doing research at universities, but that they work in various areas of business, industry, and government, in fields such as oil exploration, engineering, computer programming, public policy. He also pointed out that communicating about the science to the community is as important as hands-on research.

Sara, who has a social science background, enlightened those who assumed that a degree in a "core science" was necessary to work at a place like SCEC. She expanded on Mark's idea about communication, demonstrating that when dealing with an issue like earthquake outreach, communication skills are vital. She touched on areas of study such as the behavioral and social sciences and the roles that they play, especially in the practical applications of earthquake science.

The pair finished with a short lesson in earthquake preparedness, distributing the publication *Putting Down Roots in Earthquake Country* and copies of this newsletter. Sara has also arranged for two more guest presentations, another on "Careers in Science" for high school students and one on "Earthquake Basics" for the elementary school level, with John Galeztka of the USGS as a guest speaker.

The camp and its guest speakers program are features of the center's new public education program. Besides dispelling common myths about scientists, Mark and Sara reported being impressed that the students seem to believe that scientists have "open minds" and that their main goal is to "better humanity."

SCEC would like to congratulate and thank Joe Peacock, coordinator of the Science Camp, for providing a wonderful summer alternative for kids interested in science.

Review by Educators

DESC Online Education Modules Are One Step Closer to Public Release

In May and June, the SCEC Outreach Program sponsored two full-day workshops to bring together educators so that they could evaluate and advise on the development of earth science education modules in progress.

Until then, the modules had undergone only scientific review. The workshops provided the authors their first opportunity for direct discussions with the potential users of their products.

Caltech's Egill Hauksson, Katrin Hafner, and John Marquis, the developers of a module on investigating earthquakes through regional seismicity met with teachers and other educators on May 9. Those developing a module on SCIGN's use of GPS data, JPL's Mike Watkins, Andrea Donnellan, and Maggi Glasscoe, attended a similar workshop on June 16. Both modules were originally written for advanced high school students or community college students.

With California K-12 Alliance Regional Director Meridith Osterfeld presiding, the workshops reviewed the modules in light of the state's guidelines for teaching K-12 science as well as state and national achievement standards. Because most children are introduced to our planet and its processes in middle school, the participants focused on whether the modules could be made to fit into today's middle-school classroom.

The discussion at both workshops led to the decision to release the regional seismicity modules for the advanced level in early fall but to design a middle-school version of each as the next step for SCEC's Development of Earth Science Curricula (DESC) Online project. The SCIGN module has already been released, and plans are in the works for the development of a middle-school version of it as well.

As part of the process for making the modules more accessible to middle-schoolers, the workshops produced a "storyline" for each module, i.e., a conceptual flow to make the learning process more like a storytelling experience. The storylines are being integrated into the modules. The higher-level modules will be used to help train teachers to use the middle-school modules. Pilot testing of the modules will continue in schools throughout Los Angeles County during 1998-99.

SCEC and LANL Workshop

Urban Infrastructure to Be Focus

On Friday, September 18, 1998, SCEC and the Urban Security Group of the Los Alamos National Laboratory will sponsor a half-day workshop focusing on a multidisciplinary master model of seismic hazards in southern California. The session, held from 1:00 to 5:00 p.m. at the Pasadena Holiday Inn, will follow the annual meeting of the Western States Seismic Policy Council.

SCEC and Los Alamos are collaborating to develop a comprehensive model for simulating urban disasters. Linking multiple models developed by environmental engineers, geologists, software designers, natural hazard specialists, mathematicians, hydrologists, civil engineers, and transportation experts, the sponsors hope to integrate earth science data for use in probabilistic seismic hazard analysis. The most important outcome of the joint effort will be development of a computer-based, multilayered geographic information system database for use by the infrastructure and emergency response communities.

The SCEC-Los Alamos collaboration was driven by concerns for the vulnerability of the highway and utility systems in southern

SCEC News Briefs • SCEC News Briefs

California. At a workshop last January, the two sponsors invited end-users such as Caltrans, utility representatives, and disaster response groups to discuss an approach for linking earth science models.

A continuation of this effort, the September 18 workshop will refocus efforts on end-user input and identification of possible funding mechanisms. Invited guests will include representatives from the California Office of Emergency Services, California Division of Mines and Geology, Caltrans, California Energy Commission, city and county of Los Angeles, utilities, Red Cross, PEER, TriNet, and FEMA. Hors d'oeuvres and refreshments will be served following the workshop.

Through its collaboration with Los Alamos, SCEC continues its efforts to develop a realistic scenario for a Los Angeles-based earthquake. The Los Angeles Earthquake Scenario includes a case study, a scenario earthquake, a demonstration project, and the beginnings of a technology transfer project. This will lead to publications in professional journals, hands-on tools for emergency planners, and models for post-event crisis management and restoration of the damaged environment.

"DESC Online" Product

SCEC Demonstrates Education Modules at IRIS Annual Meeting

In July, the Education and Outreach Program the Incorporated Research Institutions for Seismology (IRIS) sponsored a workshop entitled "Seismology Software for the Classroom: a Workshop for Developers and Users." The workshop served as a promotional tool for the development of educational seismology software for the undergraduates.

Held on the campus of UC Santa Cruz, the workshop brought scientists and programmers together with end-users to explore the range of currently available software and exchange ideas for future development. Participants investigated the features of each application and explored ideas about how to use it in the classroom. The software developers included SCEC's DESC Online (Development of Earth Science Curricula Online) team. Web author John Marquis, manager Katrin Hafner, and Outreach Specialist Sara Tekula showcased DESC Online software and shared ideas with other developers and users.

About 20 users and developers met the Ming Ong Computer Lab on campus to see each other's software in action. Applications for both major personal computer platforms were presented, including *MatSeis* (Mark Harris of Sandia National Laboratories), *Wiggles* (Chuck Ammon of St. Louis University), *WinQuake 32* (Larry Cochrane at Public Seismic Network), *DIMAS* (Dima Droznin, Petro-Pavlovsk, Kamchatka, Russia), and *Seismic-Eruption* (Alan Jones at SUNY-Binghampton). Web-based applications like SCEC's *Investigating Earthquakes through Regional Seismicity* and the Live Internet Seismic Server (Bob Woodward, Albuquerque Seismological Lab) demonstrated how real-time data could be incorporated into the classroom setting to create a dynamic natural laboratory.

Overall, the workshop served as a forum for undergraduate-level professors to learn from each other's "home-grown" applications. IRIS will continue to facilitate dialogue between these groups and hold similar workshops for K-12 and adult education.

For more information about SCEC's educational software or educational programs in general, contact Sara Tekula at 213-740-2099.

CDMG News

Maps of Known Active Fault Near-Source Zones Released

The California Division of Mines and Geology, in cooperation with the Structural Engineers Association of California, released *Maps of Known Active Fault Near-Source Zones in California and Adjacent Portion of Nevada, 1998.*

The book contains more than 200 maps (11" x 17" at 1:150,000). The publication will enable building professionals involved in projects in Seismic Hazard Zone 4 to determine whether a given building site is in a known active fault near-source zone. The book explains the background of the maps and a step-by-step procedure for using them. To obtain a copy, write the International Conference of Building Code Officials, 5360 Workman Mill Rd., Whittier, CA 90601-2298 or call 800-284-4406.

New Format, More Information

What's New on the SCEC Web site

The SCEC Web site (www.scec.org) is undergoing a major renovation. Several sections have been added or expanded to include more information. The cosmetic renovation is complete; however the site is and will be constantly updated. Recent additions include:

- **SCEC publication list** of research papers in scholarly journals in a format that allows viewers to search and sort
- **Earthquake resources** categorized under the headings of preparedness, science, engineering, policy and legislation, discussion groups, and off-line resources
- **SCEC news briefs** and other earthquake-related news
- **SCEC Quarterly Newsletter**—now available for viewing online, in PDF format. The current issue is viewable by newsletter subscribers only; past issues are viewable by anyone.
- **Core institutions** list with links to senior scientists (soon to include all scientists, researchers, students, and specialists)
- **SCEC databases** and resources online
- **Education resources** available on the redesigned Outreach Program pages
- **Outreach stories** by SCEC scientists

Comments or updates for the SCEC Web site can be emailed to Mark Benthien at benthien@usc.edu.

Also Of Interest . . .

Federal Disaster Insurance

Homeowners Insurance Availability Act Sees Last Action for This Session

The House Banking Committee recently completed a markup on the Homeowners Insurance Availability Act. Some members questioned the need for the bill. Its sponsors admitted the measure is unlikely to see further action this year. One issue of concern was the fact that as written, the federal government would not begin to pay until a disaster had already cost states and private insurers $2 billion. Judging from the cost of recent major disasters, all but three states—California, Florida, and Hawaii—would have been excluded from the full benefit of the program. The committee adopted an amendment that would allow the Secretary of the Treasury to admit states into the program when the cost of a disaster topped the estimate for a 100-year event.

CUSEC News

Reports on Earthquake Planning and Building Safety Released

Two reports were recently released to guide state and local government officials in the central and southern U.S. in identifying strategies for reducing earthquake hazards. *Local Earthquake Hazard Reduction Plans, 1997* and *Seismic Safety of Existing Buildings, 1997* were produced by the Department of Urban and Regional Planning at the University of Illinois, Urbana-Champaign, under a grant from USGS. They are distributed by the Central United States Earthquake Consortium.

The primary audience for the books is CUSEC states (Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee) and CUSEC associate states (Alabama, Georgia, Louisiana, Nebraska, North Carolina, South Carolina, Ohio, and Oklahoma). They should also be useful to officials in other communities with limited resources.

Local Earthquake Hazard Reduction Plans, 1997 provides guidance for local government officials in coordinating and prioritizing the actions suggested in previous reports in the central U.S. series, such as adopting seismic codes, strengthening existing buildings, and developing programs to reduce nonstructural hazards in buildings. Practical strategies and specific actions for addressing seismic safety are outlined in priority order. The handbook also contains a step-by-step planning process for seismic safety, as well as a detailed directory of sources for additional information, and an excerpt listing the required elements of a general earthquake safety plan from the *California General Plan Guidelines, 1990.*

Seismic Safety of Existing Buildings, 1997 provides guidance in developing strategies for seismic rehabilitation of existing buildings, specifically for the CUSEC states. This handbook identifies provides details from planning through implementation, including training and incentives. Illustrated examples of seismically strengthened buildings in the central U.S. are provided. The report concludes with a glossary and detailed appendixes that contain excerpts of documents that describe seismic rehabilitation efforts in other communities, such as the mitigation of unreinforced masonry in Oakland, CA, and identification of seismic hazards in Palo Alto, CA. A guide to finding seismic rehabilitation designers and contractors is also included. A limited number of these and other reports in the *Reducing Earthquake Hazards in the Central U.S.* series are available free from: CUSEC, 2630 E. Holmes Rd., Memphis, TN 38118, 901-544-3570; or email cusec@ceri.memphis.edu. CUSEC's web site is www.cusec.org

PEER and SCEC/LANL Earthquake Risk Projects to Be Coordinated

SCEC Outreach Director Jill Andrews and Los Alamos National Laboratory (LANL) representatives Eric Jones and Dick Beckman participated in the Workshop on Earthquake Risk to Highway Transportation Systems sponsored by the Pacific Earthquake Engineering Research Center on July 10–11 at Stanford University.

The purpose of the workshop was to bring together researchers and practitioners from the academic, public, and private sectors to identify critical issues in: (1) earthquake risk analysis of transportation systems; (2) evaluation of methods leading to earthquake preparedness; and (3) development of technologies that will enable efficient and effective post-disaster response, recovery, and reconstruction.

On the first day, the program included presentations given by several organizations that require information on transportation systems subjected to severe earthquakes on the state of current practice and their needs. Then working groups addressed issues related to transportation system modeling, transportation systems under emergency response, and long-term economic effects from failure of transportation systems.

Because SCEC and LANL launched an initiative with similar goals last January, they plan to cooperate with the PEER project to minimize duplication of effort. For more information on the SCEC-LANL partnership, please see the article on earthquakes and the urban infrastructure of this issue. PEER workshop organizers were Anne Kiremidjian (Stanford), Sam Chiu (Stanford), and James Moore (USC). For more information on the PEER workshop, please contact Anne Kiremidjian or Carol Strovers at the Blume Center, Stanford University, phone 650-725-9755 or http://blume.stanford.edu.edu.

Preparedness Case Studies from Canada

The Canadian Centre for Emergency Preparedness now distributes a free weekly electronic magazine. Each issue will present a case study on a recent, real-life major disaster or related topic from the fields of emergency management, business continuity, or emergency health care. CCEP publishes a quarterly print magazine *CCEP News* that is also available on the Internet. For a free copy of the *CCEP News* magazine or to sign up for the weekly electronic magazine, visit the center's web site—www.ccep.ca.

1997 Los Angeles Basin Passive Seismic Experiment:

By Monica Kohler

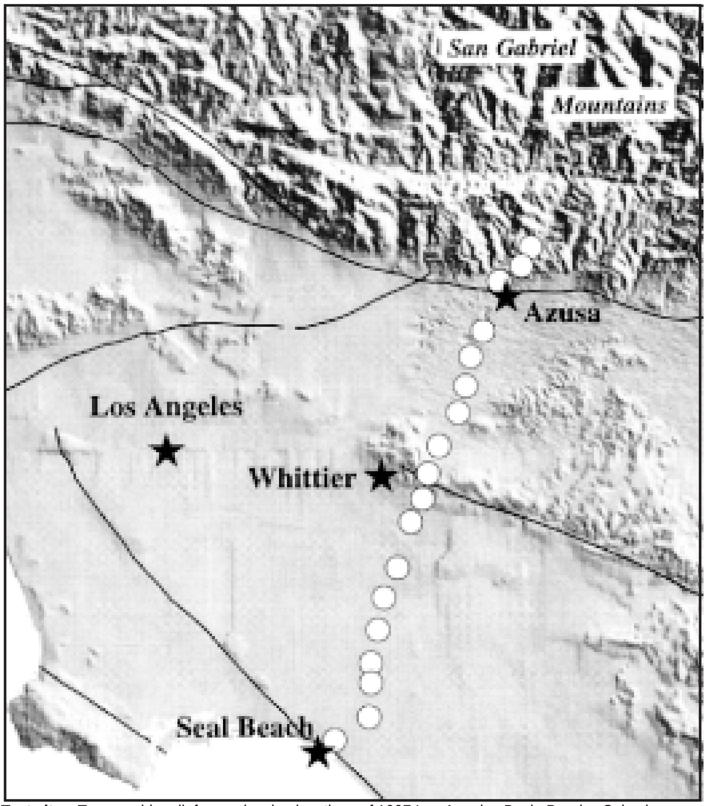
Shallow subsurface structures can sometimes focus seismic waves produced by earthquakes, resulting in enhanced earthquake damage. For example, the large amount of damage that occurred in Santa Monica after the Northridge earthquake may have been caused by focusing of seismic energy.

To prepare for such potential hazards, estimates of how hard the ground will shake at specific sites during earthquakes can be made from seismic data. Although significant progress has been made in understanding how faulting occurs in southern California, the San Gabriel Valley-northern Orange County region is one where there is still a paucity of good seismic data. The data are necessary to elucidate crustal and upper mantle structure needed in ground motion prediction, model validation, and tectonic evolution studies. The 1997 Los Angeles Basin Passive Seismic Experiment was designed to fill the gap.

The high-density LABPSE array, composed of SCEC short-period seismometers, was installed across the entire L.A. basin from March to November 1997. The array was designed and maintained by UCLA seismologists to investigate shallow Earth structure beneath the San Gabriel and L.A. basins.

We recorded local, regional, and teleseismic earthquakes continuously during the experiment (see sidebar "The Stats"). Most of the 18 stations, including those in the deep portions of the basins, recorded both local and teleseismic events with unprecedented clarity and waveform coherence. The goals of the experiment were to:

- Quantify amplification of ground motion from variations in sedimentary environments and subsurface structures.
- Examine the tectonic extensional and compressional history of the L.A. basin and San Gabriel Mountains by tomographic imaging.



Test sites. Topographic relief map showing locations of 1997 Los Angeles Basin Passive Seismic Experiment stations (circles) and nearby cities (stars).

The Array

The LABPSE array spans the L.A. basin between Seal Beach and Azusa with an average station spacing of 3-4 km. This is a much denser seismic array than any other in the region. The close spacing of seismometers is providing highly detailed information about the geometry of structures several kilometers below the surface. The high density of stations makes it possible to observe amplitude variations on length scales of a few kilometers and to obtain travel times in seismically and culturally noisy regions by cross-correlation with quiet stations using the highly coherent waveforms.

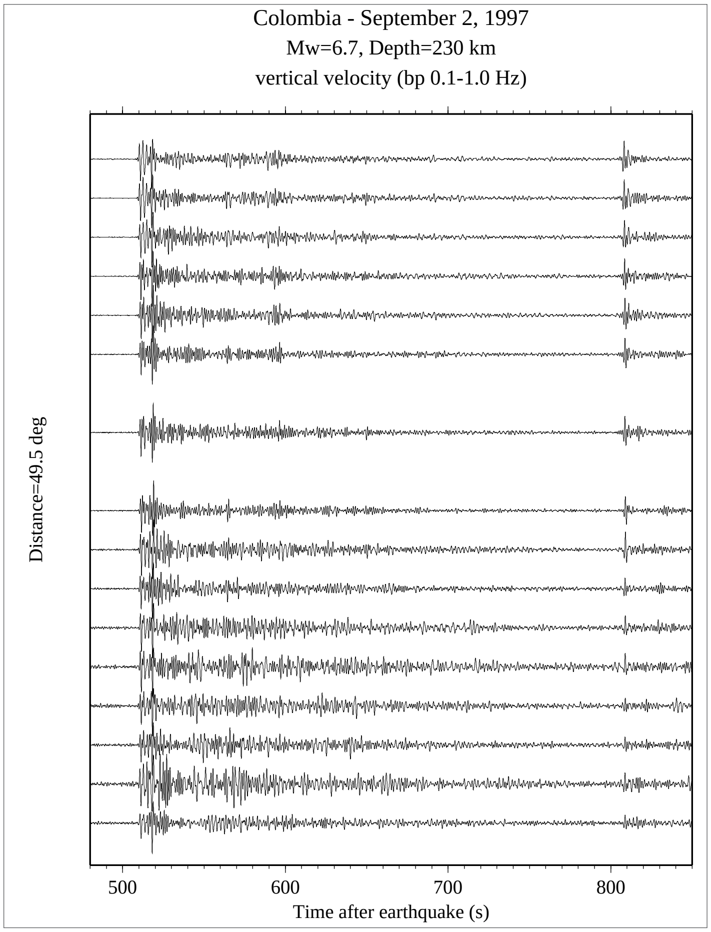
We chose this array location because it spans the entire L.A. basin, and it covers an area known for its unique geology and plate tectonics. It was also the site of one leg of the 1994 Los Angeles Region Seismic Experiment (LARSE), in which onshore and offshore explosions were recorded along essentially the same line for very detailed structure in the upper 20 km of the Earth's crust. We also needed the relatively long nine months of experiment time so that a large number of teleseisms from large earthquakes would be seen at the noisier basin stations.

The southern foothills of the San Gabriel Mountains are a Miocene depositional basin with widely varying sedimentary thickness and lithology (Yerkes and others, 1965). The high-angle, reverse San Gabriel frontal fault segment of the Sierra Madre-Cucamonga fault system defines the southern base of the San Gabriel Mountains. It dips northward into the San Gabriel Mountain's granitic and metamorphic rocks and is adjacent to unconsolidated alluvial fan deposits lying to the south, characterizing the northern San Gabriel Valley

The LABPSE Stats

- 18 short-period, 3-component SCEC seismometers (L4C3D 1-Hz sensors, Reftek Data Acquisition Systems with 16-bit and 24-bit digitizers, GPS receivers)
- Data collection by field disk swaps
- 3-km average station spacing throughout L.A. basin
- 50-km total array length from Azusa to Seal Beach. Most locations were backyards with continuous AC power sources and battery backup
- 9 months of teleseismic, regional, and local event recording (March-November 1997)
- Continuous recording at 25 sps, triggered at 50 sps

Subsurface Imaging in a Densely Populated Urban Setting



Teleseismic data. A profile of seismograms recording an event that occurred in Colombia on September 2, 1997 (M 6.7). They are arranged in order with the northernmost stations on top.

(Yerkes and others, 1965). The L.A. basin and San Gabriel Mountains are characterized by markedly different geological blocks and the changing geology is reflected in profiled seismograms across the array.

The northernmost San Gabriel Mountain foothill stations in Azusa are on bedrock or thin alluvial fan sediments and display the highest signal-to-noise ratios. They are followed to the south by several stations sitting on ~3 km of sediments that make up the San Gabriel Valley, a small sedimentary basin within the larger L.A. basin. The increase in sedimentary thickness (i.e., the increased depth of basement) results in scattered waveforms, showing more phase complexity than the bedrock stations.

The central three stations in the Puente Hills are separated from the bulk of deeper-sediment (up to ~7 km) basin stations farther south by the Whittier fault. The southernmost stations are near the coast in Seal Beach and cross the Newport-Inglewood fault. Waveform coherence is spectacular across the array, regardless of environment. The figure "Teleseismic data" shows teleseismic arrivals from an event that occurred in Colombia, for example.

The Geology

The mid-Tertiary East Pacific Rise collision with the North America plate and subsequent crustal extension are supported by geological evidence for mid-Miocene rifting and volcanism (Wright, 1991) associated with the opening of a rift basin by extension accompanied by high heat flow (Henyey, 1976). Crustal extension coincides with episodes of pervasive, clockwise block rotation throughout southeast California and is related to changing Farallon subduction deformation style (Luyendyk, 1991).

The L.A. basin contains numerous high-angle faults that make up a shattered, brittle crust often associated with crustal thinning and block faulting over a mobile layer such as is thought to occur in the Basin and Range province. Models of their geological and tectonic histories are most effectively constrained by data obtained from dense arrays such as LABPSE. This experiment will help determine whether crustal thinning from extension has occurred beneath the L.A. basin.

In the Backyard—Literally

One of the unique aspects of this experiment was the interaction with the homeowners whose backyards we used for seismometer locations. We are grateful to them for their enthusiastic permission to use their properties. One homeowner helped us build a stand to raise our GPS receiver, and his daughter helped us test our equipment by bouncing her ball as a vibration source.

The use of private homes had additional perks besides the obvious scientific advantages. One of our favorite sites was a home in La Puente where the owners had a lovely garden with wonderful herbs, trees, and flowers. The seismometer was in the corner of the yard and was guarded by a faithful duck whose house was next to the data recording system. We were treated to homegrown

Local help. In La Puente, homeowner Joe Baeli, assisted by daughter Elizabeth, is constructing a stand to raise our GPS receiver. Aaron Martin of the Institute of Crustal Studies is also pictured.

Photos: Monica Kohler

In a trailer park. The second station from the north end of the array. Elizabeth Cochran and Carmen Alex are pictured.

tomatoes in the garden of a Whittier homeowner. A Hacienda Heights homeowner offered us the use of his pool. However, we had to be careful of black widow spiders nesting in the cool, dark recesses of our equipment.

The most beautiful site was the northernmost station in the San Gabriel Mountains next to Morris Dam, but a forest fire prevented us from getting to that site for a week during the late summer. The most unusual sites were the southernmost three. One was next to an Armed Forces Reserve helicopter flight simulator building actively used in military training, and two were among nuclear missile storage bunkers purposely disguised with slanted grassy roofs so that they would not be easily observed by satellites.

The homeowners were eager to talk about their experiences with recent local earthquakes and wanted more information on current seismicity, geology, and relative shaking levels in their communities. It was satisfying to be able to show them actual seismograms recorded in their yards from felt earthquakes. Most were eager to find out how their house had fared relative to adjacent cities, given the geological environment and type of house they lived in. We were impressed with the depth and number of questions we were asked about regional faulting and seismicity. Los Angeles residents obviously know much more about earthquakes than they did 10 to 20 years ago. By installing our stations in backyards, we were able to take advantage of continuous power, equipment security, and easy access to the recording disks, which were swapped about once every three weeks.

The local events are being used by UCLA seismologists to quantify ground motion amplification in densely populated areas near the Whittier and Sierra Madre faults. Preliminary analysis shows an unexpected change in waveform character between the Puente Hills stations and adjacent stations to the north (San Gabriel Valley) and south (southern L.A. basin).

Results

Several earthquakes that occurred near the array have surprisingly impulsive P and S arrivals on San Gabriel Valley and L.A. basin records, but scattered or emergent arrivals for stations in the Puente Hills. A defocusing structure such as a sharply folded anticline would explain this observation. In addition, the horizontal waveforms for the basin stations are most amplified between Cerritos (south of Whittier) and Cypress (north of Seal Beach), the segment that corresponds to the region of maximum basin sedimentary thickness along the line.

The teleseismic data combined with Southern California Seismic Network data will be used in tomographic inversions for subcrustal lithospheric heterogeneity with greatly increased ray-path coverage and resolution beneath the deeper portions of the L.A. basin. Although the L.A. basin is a heavily studied region, there is a surprising dearth of teleseismic data. The waveforms from local networks are often difficult to read; if there is a question about the arrival time of a specific phase, none is reported. Moreover, no other networks are nearly as dense as LABPSE with three-component recording, precluding the study of small-scale structures in the lower crust/upper mantle. The three-dimensional images of seismic heterogeneity make it possible to evaluate the role of recent tectonics in the geologic history of the eastern L.A. basin.

The Preliminary Determination of Epicenters (PDE) Catalog produced by the USGS National Earthquake Information Center (NEIC) shows that 230 teleseismic events with magnitudes greater than 5.5 occurred during this experiment. According to catalog data supplied by the SCEC Data Center, 17 regional events and 2,280 locals events of M >2.0 occurred during the recording period. Notable local events included the March 18, 1997, Calico earthquake (M 5.3), as well as the April 26 and April 27, 1997, Northridge aftershocks (M 5.1 and 4.9).

Data processing is now complete, and the data will be archived at the Incorporated Research Institutions of Seismology (IRIS) Data Management Center and UCLA. Processing included making time corrections using the GPS receiver timing data at each station and cutting the continuous data into 150-second (local and teleseismic events) and 1-hour files (teleseismic events).

The waveforms will be used by SCEC researchers to test numerical predictions of ground motion amplitude variations caused by local earthquakes for a large range of azimuths. The clearly recorded teleseisms in the basin make an ideal test case to validate ground motion predictions using various 3D southern California upper-crustal velocity models. The operational success of arrays such as this and the LARSE passive array illustrate the potential value of a continuously migrating dense local array, making it possible to deploy seismometers for long periods in regions where instrumentation is sparse.

References

Yerkes, R. F., T. H. McCulloh, J. E. Schoellhamer, and J. G. Vedder, Geology of the Los Angeles basin California—an introduction, *Geol. Surv. Profess. Pap.*, 420-A, 1965.

Wright, T. L., Structural geology and tectonic evolution of the Los Angeles basin, California, in: *Active Margin Basins*, K. T. Biddle (Editor), *AAPG Memoir 52*, 1991.

Henyey, T. L., Heat flow and tectonic patterns on the southern California borderland, in *Aspects of the Geologic History of the California Continental Borderland*, D. G. Howell (Editor), *American Association of Petroleum Geologists Miscellaneous Publication 24*, 1976.

Luyendyk, B. P., A model for Neogene crustal rotations, transtension and transpression in southern California, *Geol. Soc. Am. Bull.*, 103, 1528–1536, 1991.

Acknowledgments—We thank Paul Davis, Aaron Martin, Bryan Kerr, Shirley Baher, Steve Persh, Andy Rigor, Geoff Ely, Kirsten Zellmer, Elizabeth Cochran, and Carmen Alex for their assistance during this experiment. The equipment and maintenance of the experiment were made possible by the existence of the SCEC Portable Broadband Instrument Center at the Institute for Crustal Studies at UC Santa Barbara. Funding was provided by U.S.G.S. and SCEC.

Featured Fault

Late Quaternary Growth of the San Joaquin Hills Anticline: New Potential Source of Blind Thrust Earthquakes in the L.A. Basin

Compiled by Ed Hensley
Reviewed by Karl Mueller

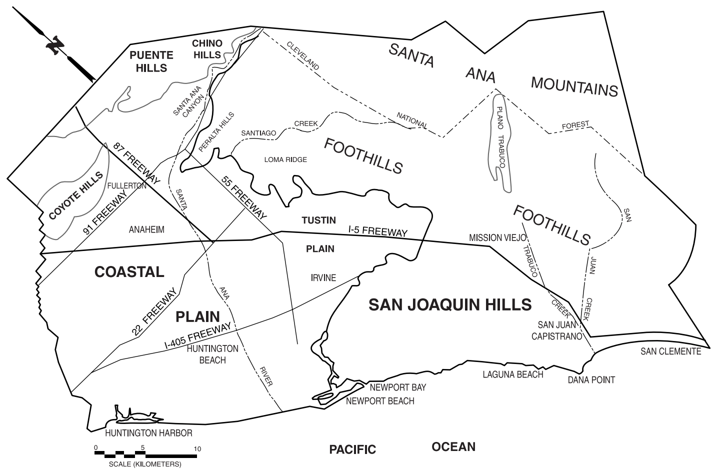
Karl Mueller had been studying the structural geology of the southwestern Los Angeles basin, originally focusing on the Compton-Los Alamitos Hills structure. As an extension of that work, Mueller suspected blind thrusting could have been part of the mechanism that created the topography known as the San Joaquin Hills farther south in Orange County.

Lisa Grant and others had similar suspicions for different reasons (see related story in SQN 4:1, p. 12). In 1996, several of them teamed up via complementary SCEC proposals to compile a large but inconsistent body of existing data and to take a closer look at the structures in the field. Their primary purpose was to determine whether the available information supported their hypothesis that a Northridge-like active blind thrust exists under the hills. On all existing fault maps, the San Joaquin Hills are listed as inactive.

Specifically, Mueller performed structural and geomorphic analysis of the northern San Joaquin Hills to define:

- Kinematic mechanisms that build the San Joaquin Hills anticline
- The recency of uplift of the fold (i.e., whether Late Quaternary sediments were deformed in a manner consistent with long-term uplift)
- Long-term rates of uplift and its relation to fault slip rates on the blind thrust proposed to underlie the fold
- The geometry of the proposed blind thrust

The work included structural modeling of 3D fold geometry, mapping of deformed drainage networks, generation of high-resolution digital elevation models and triangulated irregular networks, and



compilation of water-well data (from the Orange County Water District). These studies were coordinated with U-series age dating (George Kennedy, Larry Edwards and Hai Cheng) as well as geotechnical data compilation and Late Quaternary deposit mapping (Lisa Grant, Rosalind Munro, and Eldon Gath).

Structural and geomorphic analysis of marine terraces and stream drainage networks suggests the San Joaquin Hills anticline is an active fold. Marine terraces incised into the SW-dipping flank of the fold form well-defined platforms that can be traced around the NW-dipping plunge panel of

FAULT STATS

Rate of uplift:
0.25mm/yr

Slip rate:
0.51mm/yr (interpolated)

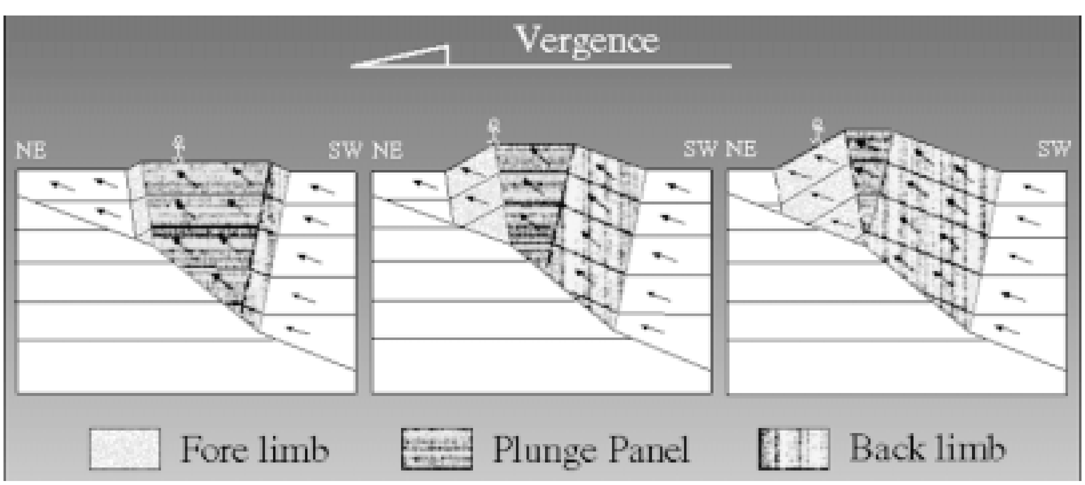
Max credible earthquake:
~M_w 7.1

Fault length:
~38 km

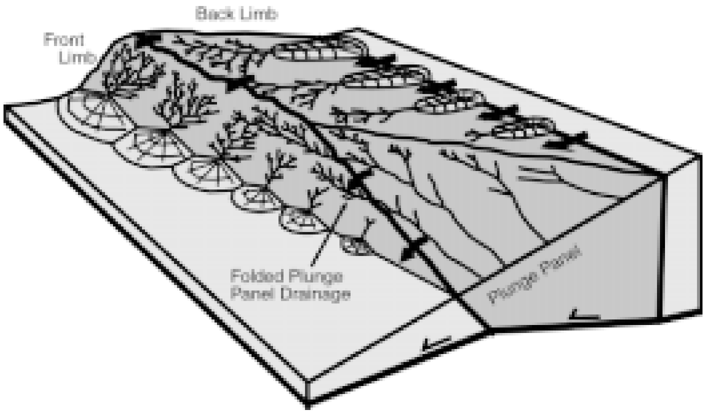
Fault rupture depth:
17-5 km, with 30° dip

Minimum fault width:
~8 km

Nearby communities:
along I-5 near Irvine



Simplified serial cross sections illustrating the kinematics of a simple fault-bend fold. The upper surface of the plunge panel migrates in the direction of the movement on the thrust. The implication is that the plunge panel is consumed by bending across the active axial surface pinned to the top of the thrust ramp at depth. This region is where more recent bending of drainage networks that were originally formed on the plunge panel are likely to be preserved.



Map view drainage geometry. Block diagram of geomorphic features formed by the interaction of folding, erosion, and syntectonic sedimentation on an active fault-bend fold. Active axial surfaces are marked by heavy lines and arrows indicating the sense of kink-band migration. Younger parts of the fold are located along active axial surfaces and at the end of the plunge panel, where structural relief decreases to zero. Stream drainage networks are developed on actively eroding parts of the fold, where they define the location of active axial surfaces. The drainage networks originally formed on the plunge panel are folded onto the front limb. These short-lived disequilibrium channel networks define the sense of kink-band migration and the location of bends in the blind thrust at depth. Erosional capture of plunge panel drainage networks also occurs along the crests of the front and back limbs and is apparent in the San Joaquin Hills.

the fold. Two of the terraces can be traced onto the NE-dipping flank of the fold where they are folded downward to the east. The geometry of that folding is consistent with structural models of fault-related folds for other blind faults, suggesting that the terraces are being deformed by fault-bend folding above a NE-vergent thrust ramp. That conclusion is supported by the geometry of stream networks, which are also unique indicators of fold kinematics associated with a NE-vergent ramp.

For a laterally propagating fault-bend fold, the plunge panel is consumed by fold limbs across active axial surfaces (see figure). Drainage networks mapped on the youngest part of the forelimb (produced by consumption of the plunge panel) record a disequilibrium in which channels are oriented parallel to strike, a condition that can only be short-lived. The older portions of the forelimb display drainages that have reestablished new channels consistent with its NE dip. Map patterns of the stream channels in disequilibrium suggest the east edge of the plunge panel is an active axial surface, consistent with material moving through the top of the ramp on a NE-vergent blind thrust.

Rates of uplift derived from U-series dating of corals from deposits that overlie the terrace platforms yield independent and consistent determinations of 0.25mm/yr (see SQN 4:1, p. 12 for details of the dating process).

A fault slip rate of 0.51mm/yr is indicated for a 30-degree dipping fault, similar to a NE-vergent thrust imaged on seismic reflection profiles from the adjacent offshore area. This high-level fault lies above the well-imaged Oceanside detachment, a Miocene low-angle normal fault that dips NE. Cross sections permit the interpretation that the blind thrust beneath the San Joaquin Hills is linked at depth with the detachment as part of a wedge structure, now reactivated as a SW-vergent fault system. For earthquakes originating at the base of the seismogenic crust on the wedge structure, magnitude and recurrence must be consistent with the large fault area (maximum credible earthquake of Mw 7.1, fault length of 38 km, dip of 30°, and rupture of 17-5 km deep) and slow slip rate.

Results

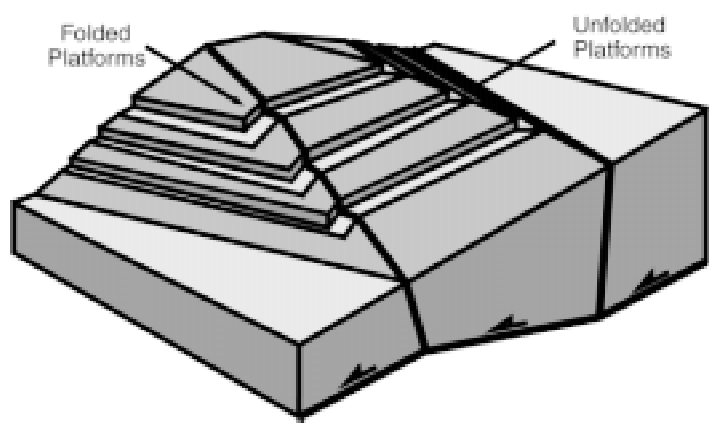
Modeling of the geometry of the San Joaquin Hills suggests they are formed by fault-bend folding. That assumption is based on the geometry of axial surfaces deforming marine terrace deposits and stream drainage networks. Based on the morphology of the anticline and the geomorphically consistent structural model, consumption of the plunge panel occurs at the top of the NE-facing fold limb. This implies that the axial surface at the top of the NE-facing fold limb is pinned to the top of a blind thrust ramp at depth.

The recency of uplift of the fold has been assessed by mapping and U-series dating of folded marine terrace deposits. These results suggest marine sediments (~80 Ka) are folded in a manner consistent with the long-term uplift history of the fold.

Well data in the water gap between Huntington Mesa and Newport Mesa also indicate the Holocene Talbert Aquifer is deformed in a style consistent with the structural models completed for this study. Besides evidence for uplift of Holocene marshes in the Newport Back Bay investigated by Lisa Grant, this aquifer data represents the strongest evidence classifying the San Joaquin Hills anticline as an active seismogenic source.

Construction of triangulated irregular networks from digital elevation models supports the initial structural modeling results and indicates that the NE-facing fold limb deforms marine terrace deposits. In this area, certain terrace platforms are folded downward to the NE from their otherwise constant elevation around the SW side of the fold.

These efforts support the mapping studies that indicate the difficulty (i.e., uncertainty) in correlating isolated terrace surfaces that do not extend along a constant elevation in this area. On the NE-facing fold limb, the folded terraces nearly merge into a single surface, but



Fault structure/plunge panel. Block diagram of marine terrace platforms incised into the limbs and plunge panel of a simple fault-bend fold (equivalent to view toward SW of the San Joaquin Hills). Active axial surfaces marked as heavy black lines. Note the folded terrace platforms located on the fore limb of the fold, and the unfolded terraces on the back limb.

still exhibit some vertical separation before being buried by alluvial sediments derived from the El Toro embayment.

These geomorphic observations have geometric implications for the otherwise inaccessible blind thrust:

- The active axial surface on the NE-facing fold limb is located at the crest of the fold (i.e., the thrust verges towards the NE)
- Minor uplift occurs on the NE-facing back limb, suggesting the dip of the blind thrust beneath this area is shallow, but not flat
- A steeper ramp segment is located beneath the area under the plunge panel and SW-facing fold limb

Conclusions

Based on the structural and geomorphic analysis, it is likely that the blind thrust proposed to exist beneath the San Joaquin Hills is active. For a range of given geometries, fault slip rates are likely to be in the range of 0.5 mm/yr. Because subsurface fault geometry is unconstrained, the area likely to rupture in a single seismic event is uncertain; however, a maximum credible earthquake for this part of coastal Orange County would extend along strike ~25 km, with a minimum fault width of ~8 km. This raises the possibility that a near Northridge-sized event is possible on a SW-dipping thrust in this region and that directed effects of strong ground motion may be severe in the densely populated urban corridor along Interstate 5 near Irvine.

Reference

Sprotte, E. C., Fuller, D. R., Greenwood, R. B. and Mumm, H. A., 1980, Classification and Mapping of Quaternary Sedimentary deposits for purposes of seismic zonation, south coastal Los Angeles Basin, Orange County, California: California Division of Mines and Geology Open File Report 80-19, 250p.

. . . continued from page 15

- Assist in workshop at Peninsula High School (tsunamis and landslides)
- Assist and consult with California State Parks Department on landslide and faulting at San Onofre
- Talk to classes at Village View Elementary School and Mesa View Middle School in Huntington Beach about earthquakes and faulting under the ocean

Pete Rodgers (UC Santa Barbara)

- Seminar to the Center for Control Engineering and Computation (Department of Electrical and Computer Engineering at UCSB): "Fundamental Limits and New Directions in Seismometry"
- Two papers to IRIS Instrumentation Workshop in Santa Fe, NM: "Seismic Sensors: Fundamental Limits and New Directions" (keynote) and "New Seismic Sensors on the Scene"
- Consult on technical matters for the Special Technology Laboratory of Bechtel Nevada Corp. (the laboratory provides technical assistance to government agencies such as DOE and DOD)

John Rundle (Univ. of Colorado)

- Teach an undergraduate course for nonmajors: "Earthquakes"
- Consultant for JPL and NASA
- As solid earth representative to the ESSAAC committee that advises the associate administrator for earth science, I attend and organize meetings and workshops

David Seymour (Dames & Moore)

- Giving presentations to elementary school classes in southern Orange County on general geology, usually visiting two or three classrooms a year and bringing in my rock and fossil collections
- Set up a booth at the UCSD's Science Fest (for elementary schools from the entire school district), displaying rocks, fossils, and geologic maps

Juracy Soares (CISESE)

- I was a SCEC intern for the summer of 1997 and have been involved in education activities in my Ensenada community.
- I've spoken in two elementary schools on safety measures to be taken in an event of an earthquake
- As professor at the Universidad Autonoma de Baja California, in the school of engineering, I orient civil engineering students to be earthquake wise when building structures

The efforts and contributions of everyone in SCEC should be recognized and acknowledged as an integral part of SCEC's outreach effort.

Jeff Stevens (Maxwell Technologies)

- Presentation entitled "Geophysics and Geophysicists" to eighth grade science class, explaining what geophysics is and what geophysicists do and trying to convey a sense of scale—how big are the largest earthquakes, how small are the signals recorded on seismograms

Joann Stock (Caltech)

- Interviews for Spanish news media about earthquakes, including specific earthquakes of interest (here or in Latin America) as well as other general questions
- Interviews in Spanish about M 4.3 earthquake in Chino: Radio-Noticias (live), Channel 52 TV (Pepe Barreto), Channel 22 TV
- Interview in Spanish about 3.2 earthquake in Brea and 3.5 earthquake in Mexicali for Radio-Noticias with Miguel Monroy
- Interview about Earthquake Preparedness Month in Spanish for RadioNoticias with Miguel Monroy

Lynn Sykes (Lamont-Doherty Earth Observatory)

- AGU meeting: presented results on changes in stress in southern California (with Jishu Deng) and on changes in frequency of moderate-size earthquakes prior to large and great shocks
- Talk on "Changes in the Frequency of Moderate-size Earthquakes Preceding Large Shocks in California" at SCEC Workshop on Earthquake Physics

Lisa Wald (U.S.G.S. Pasadena)

- Interview with student for Take Our Daughters to Work Day
- Hands-on demonstration about earthquakes for Paramount Elementary School
- Newspaper interviews related to seismic activity and earthquakes in southern California
- Respond to requests for data from scientists and private companies and requests for information from the public
- Participate in USGS Ask-a-Geologist program
- Webmanager for USGS Pasadena Field Office website and respond to requests for information sent to webmanager from web page
- Webmanager for TriNet website
- Worked on development of USGS Northridge Research Products website

Kristin Weaver (USC)

- Our active tectonics group (headed by Jim Dolan) has been talking to people around our trench sites and handing out *Putting Down Roots in Earthquake Country* to interested persons at our trenches. This was particularly effective during my project on the Raymond fault in August 1997 at the L.A. County Arboretum in Arcadia. Many visitors to the Arboretum stopped to look at our excavation and discuss our work.
- We have to coordinate with land owners, including cities and individual citizens, which always starts with an explanation of what we hope to accomplish with our fault study. We also have standing offers to the municipalities in which we have (and will) conduct paleoearthquake studies to give public seminars to their residents on earthquakes, earthquake safety, and our research.

Robert Yeats (Oregon State Univ.)

- Publishing the book *Living with Earthquakes in the Pacific Northwest*, through Oregon State University Press. Although it focuses on the Northwest, many chapters (insurance, forecasting, retrofitting house, preparedness, engineering of large structures, role of federal, state, and local government) apply as much to California as to the Northwest.
- My publisher wants to do a companion volume, *Living with Earthquakes in California*.

SCEC Research Publications & Abstracts

The following is a list of recent publications based on SCEC-funded research. SCEC authors must obtain SCEC contribution numbers for all papers in order to acknowledge SCEC funding. In return their papers are added to the SCEC Publication Database. This database is reported to the NSF during each SCEC evaluation. To receive a SCEC contribution number for a recently submitted paper (or for a published paper that did not originally receive a SCEC number), email Mark Benthien (BENTHIEN@USC.EDU) with the authors, title, publication name, ***abstract*** (very important) and any other bibliographic information available. The SCEC number will be returned via email along with the proper NSF/USGS/SCEC acknowledgement statement. The SCEC Quarterly Newsletter now publishes the references only for published articles, no longer listing ones that are submitted, in review, in press, etc. The complete list (both searchable and sortable) is available at WWW.SCEC.ORG/RESEARCH/PAPERS.HTML, and will no longer be printed in the newsletter in its entirety each year. A hardcopy version of the list can be obtained by calling 213-740-5843 or emailing SCECINFO@USC.EDU.

376. Fuis, G. S., Murphy, J. M., Lutter, W. J., Moore, T. E., Bird, K. J., and Christensen, N. I., Deep seismic structure and tectonics of northern Alaska: crustal-scale duplexing with deformation extending into the upper mantle, Journal of Geophysical Research, 102, pp. 20ff, 1997.

Seismic reflection and refraction and laboratory velocity data collected along a transect of northern Alaska (including the east edge of the Koyukuk basin, the Brooks Range, and the North Slope), yield a composite picture of the crustal and upper mantle structure of this Mesozoic and Cenozoic compressional orogen. Major tectonic features that are imaged are as follows: (1) Northern Alaska is underlain by nested tectonic wedges, most with northward vergence (i.e., with their tips pointed north). (2) High reflectivity throughout the crust above a basal decollement, which deepens southward from about 10-km depth beneath the northern front of the Brooks Range to about 30-km depth beneath the southern Brooks Range, is interpreted as structural complexity due to the presence of numerous tectonic wedges, or duplexes. (3) Low reflectivity throughout the crust below the decollement is interpreted as minimal deformation, which appears to involve chiefly bending of a relatively rigid plate consisting of the parautochthonous North Slope crust and a 10- to 15-km thick section of mantle material. (4) This plate is interpreted as a southward verging tectonic wedge, with its tip in the lower crust or at the Moho beneath the southern Brooks Range. In this interpretation, the middle and upper crust—or all of the crust—is detached in the southern Brooks Range by the tectonic wedge, or indentor: as a result, crust is uplifted and deformed above the wedge, and mantle is depressed and underthrust beneath this wedge. (5) Underthrusting has juxtaposed mantle of two different origins (and seismic velocities), giving rise to a prominent sub-Moho reflector.

379. Spotila, J. A., K. A. Farley and K. Sieh, Uplift and erosion of the San Bernardino Mountains associated with transpression along the San Andreas fault, California, as constrained by radiogenic helium thermochronometry, Tectonics, 17, pp. 360–378, 1998.

Apatite helium thermochronometry provides new constraints on the tectonic history of a recently uplifted crystalline mass adjacent to the San Andreas fault. By documenting aspects of the low-temperature (40-100 degrees C) thermal history of the tectonic blocks of the San Bernardino Mountains in southern California, we have placed new constraints on the magnitude and timing of uplift. Old helium ages (64-21 Ma) from the large Big Bear plateau predate the recent uplift of the range and show that only several kilometers of exhumation has taken place since the Late Cretaceous period. These ages imply that the surface of the plateau may have been exposed in the late Miocene and was uplifted only ~1 km above the Mojave Desert in the last few Myr by thrusting on the north and south. A similar range in helium ages (56-14 Ma) from the higher San Gorgonio block to the south suggests that its crest was once contiguous with that of the Big Bear block and that its greater elevation represents a localized uplift that the Big Bear plateau did not experience. The structure of the San Gorgonio block appears to be a gentle antiform, based on the geometry of helium isochrons and geologic constraints. Young ages (0.7-1.6 Ma) from crustal slices within the San Andreas fault zone indicate uplift of a greater magnitude than blocks to the north. These smaller blocks probably experienced >3-4 km of uplift at rates >1.5 mm/yr in the past few Myr and would stand >2.5 km higher than the Big Bear plateau if erosion had not occurred. The greater uplift of tectonic blocks adjacent to and within the San Andreas fault zone is more likely the result of oblique displacement along high-angle faults than motion along the thrust fault that bounds the north side of the range. We speculate that this uplift is the result of convergence and slip partitioning associated with local geometric complexities along this strike-slip system. Transpression thus appears to have been accommodated by both vertical displacement within the San Andreas fault zone and thrusting on adjacent structures.

380. Dolan, J. F. and Pratt, T. L., High-resolution seismic reflection profiling of the Santa Monica Fault Zone, West Los Angeles, California, Geophysical Research Letters, 24, pp. 2051–2054, 1997.

High-resolution seismic reflection data obtained across the Santa Monica fault in west Los Angeles reveal the near-surface geometry of this active, oblique-reverse-left-lateral fault. Although near-surface fault dips as great as 55∞ cannot be ruled out, we interpret the fault to dip northward at 30∞ to 35∞ in the upper few hundred meters, steepening to 65∞ at 1 to 2 km depth. A total of ~180 m of near-field thrust separation (fault slip plus drag folding) has occurred on the fault since the development of a prominent erosional surface atop ~1.2 Ma strata. In the upper 20 to 40 m strain is partitioned between the north-dipping main thrust strand and several closely spaced, near-vertical strike-slip faults observed in paleoseismologic trenches. The main thrust strand can be traced to within 20 m of the ground surface, suggesting that it breaks through to the surface in large earthquakes. Uplift of a ~50,000-year-old alluvial fan surface indicates a short-term, dip-slip rate of ~0.5 mm/yr, similar to the ~0.6 mm/yr dip-slip rate derived from vertical separation of the oxygen isotope stage 5e marine terrace 3 km west of the study site. If the 0.6 mm/yr minimum, dip-slip-only rate characterizes the entire history of the fault, then the currently active strand of the Santa Monica fault probably began moving within the past ~300,000 years.

401. Duebendorfer, E.M., J. Vermilye, P.A. Geiser, and T. L. Davis, Evidence for aseismic deformation in Southern California: Implications for seismic risk assessment, Geology, 26, pp. 271–274, 1998.

Recent studies in southern California suggest that long-term deformation rates are far in excess of that which can be accounted for by historical seismicity, and thus, a deficit of moderate and/or large earthquakes exists in southern California. Although possible, this conclusion is not unique because aseismic deformation may have contributed to bulk regional strain. We examined Cretaceous to Pleistocene sedimentary rocks exposed in the Ventura basin, along four cross-strike traverses to evaluate the possibility that aseismic deformation contributed to regional shortening. Our field and microstructural investigations suggest that aseismic deformational mechanisms, particularly pressure solution, contributed significantly to permanent shortening strain during the late Neogene and that the proposed seismic deficiency may be overestimated.

406. Stein, R. S., and T. C. Hanks, M 6 Earthquakes in Southern California During the 20th Century: No Evidence for a Seismicity or Moment Deficit, Bulletin of the Seismological Society of America, 88, pp. 635–652, 1998.

A broadly based report on seismic hazards in southern California (WGCEP, 1995) concluded that the predicted seismicity exceeds that observed since 1850; a subsequent independent analysis argued that infrequent huge (M>8) earthquakes are needed to explain the low rate of large earthquakes (Jackson, 1996). Frequency-magnitude relationships and earthquake reporting suggest that the 1903-1997 catalog we present here, with a b value of 1.0 and a rate of M 6 shocks of 0.42-0.49 yr-1, is nearly complete. In contrast, the 1850-1994 catalog used by WGCEP is incomplete before the turn of the century, and thus its reported seismicity rate of 0.32 M 6 shocks yr-1 is too low. Principally because the WGCEP (1995) model results in b values of up to 4.0 for regions of lesser and blind faults, the rate of M 6 shocks off the San Andreas system predicted by the WGCEP (1995) model is three times greater than that observed in this century. Because they obtained b=0.4 for M<7.3 and b=2.2 for M 7.3 on major faults, their expected rate of M 7 San Andreas shocks is twice as high as observed. Thus part of the seismicity and moment discrepancy identified by WGCEP was caused by use of an incomplete catalog, and part was caused by inappropriate b-values. We obtain a southern California moment release rate of 8-12 x 1018 Nm yr-1, which cannot be distinguished from the moment release estimated by fault slip, or the moment accumulation inferred from plate motions or geodetically measured shear strain. We thus find no evidence for a moment deficit, significant aseismic moment release, or for rare M 8 earthquakes off the San Andreas fault system. Finally, the number of M 6 earthquakes per decade does not depart significantly from a Poisson process during this century, and thus we find no evidence that the rate of seismicity is increasing, now or at any time since 1900.

409. Nielsen, S. and L. Knopoff, The Equivalent Strength of Geometrical Barriers to Earthquakes, Journal of Geophysical Research, 103, pp. 9953-9965, 1998.

We present a quantitative framework for evaluating the influence of non-planar fault geometry on repeated seismic ruptures. We model quasistatic ruptures on a non-planar fault trace imbedded in a two-dimensional elastic medium under in-plane strain. Owing to the presence of fault segments that are not parallel to the regional shear stress (i.e., bends), the apparent strength at a given point on the fault is not fixed, but fluctuates with normal stress. Compressional features behave as increasingly strong barriers to fracture unless the stored normal stress is released to unlock the fault. Since slip on the fault cannot get rid of the normal stress, this is achieved through the action of off-fault morphological features such as secondary faulting. The apparent strength of a fault bend will stabilize in a narrow interval of values after repeated ruptures, characterized by a non-dimensional “hardness” parameter, whereby the relaxation rate is scaled by the tectonic loading rate.

On a fault structure having several small, widely separated bends, three families of events can be identified whose frequency and magnitude depend on the hardness (relaxation) parameter and the geometry: small events that cluster in the tension zones of the bends, intermediate size ruptures involving a single interbend segment, and large ruptures that break through bends and link one or more interbend segments. Large multi-segment events are most likely to happen for low values of hardness (fast relaxation and slow loading).

Compressional features act as barriers to ruptures; stress is stored there until they break and trigger smoother, long reaches of the fault.

411. Lee, Y., Y. Zeng and J. G. Anderson, A Simple Strategy to Examine the Sources of Errors in Attenuation Relations, Bulletin of the Seismological Society of America, 88, no. 1, pp. 291-296, 1998.

A new method is presented in this paper to visualize two different sources in the uncertainty of attenuation regression relations. The method utilizes the residuals from regression equations, defined as the log of the ratio of observed to predicted ground motion parameters, from stations that have recorded more than one earthquake. The earthquake-to-earthquake variance is first calculated. Then the residuals are corrected with the mean residual of the corresponding earthquake. The corrected residual from one event is plotted versus the corrected residual from another event for every station that has more than one record. If site effects are perfectly represented in the regression, the resulting scatter plot will show statistically uncorrelated points, while extension along the diagonal and a positive correlation coefficient is the result of a contribution from site effects. This simple strategy allows us to visualize the uncertainty caused by the earthquake source and path in regression relations, and indicates quantitatively how much we can improve the prediction by adding additional site information. The results obtained from this method are very similar to those that are calculated directly from the method proposed by Joyner (1997). In southern California, we find that source and path effects dominate the uncertainties at high frequency, while at low frequency the regression can be still improved more significantly by correcting for the site effects.

427. Field, E. H., S. Kramer, A.-W. Elgamal, J. D. Bray, N. Matasovic, P.A. Johnson, C. Cramer, C. Roblee, D. J. Wald, L. F. Bonilla, P. P. Dimitriu, and J. G. Anderson, Nonlinear Site Response: Where We’re At, Proceedings of the 7th International Symposium on the Observations of the Continental Crust through Drilling, 69, no. 3., pp. 230-234, 1998.

432. Yehuda Ben-Zion, Properties of Seismic Fault Zone Waves and Their Utility for Imaging Low Velocity Structures, Journal of Geophysical Research, 103, no. B6, pp. 12567-12585, 1998.

A two-dimensional solution for the scalar wave equation in a model of two vertical layers between two quarter-spaces is used to study properties of seismic waves in a laterally heterogeneous low velocity structure. The waves, referred to as seismic fault zone waves, include head waves, internal fault zone reflections, and trapped waves. The analysis aims to clarify the dependency of the waves on media velocities, media attenuation coefficients, layer widths, and source-receiver geometry. Additional calculations with extreme low velocity layers provide examples that may be relevant for volcano-seismology. The interference patterns controlling seismic fault zone waves change with the number of internal reflections in the low velocity structure. This number increases with propagation distance along the structure, decreases with fault zone width, and increases (for given length scales) with the velocity contrast. The relative lateral position of the source within the low velocity layer modifies the length scales associated with internal reflections and influences the resulting interference pattern. Low values of Q affect considerably the dominant period and overall duration of the waves. Thus there are significant trade-offs between propagation distance along the structure, fault zone width, velocity contrast, source location within the fault zone, and Q. The lateral and depth receiver coordinates determine the particular point where the interference pattern is sampled and observed motion is a strong function of both coordinates. The zone connecting sources generating fault zone waves and observation points with appreciable wave amplitude can be over an order of magnitude larger than the fault zone width. Calculations for cases with layer P wave velocity of about 200 m/s, modeling vertical dike or crack with fluid and gas, show conspicuous persisting oscillations. The results resemble aspects of seismic data in volcanic domains. If these waves exist in observed records, their explicit recognition will help to separate source and structural effects, and aid in the interpretation of volcano-seismology signals. Although the trade-offs in parameters governing seismic fault zone waves are significant, each variable has its own signature and the parameters may be constrained by additional geophysical data. Simultaneous modeling of many waveforms with an appropriate solution can resolve the various parameters and provide a high resolution structural image.

437. Zhao, D., Seeking the cause of earthquakes, Science Spectra, 11, pp. 6-10, 1998.

High-resolution seismic tomography detects weak sections of the seismogenic crust, facilitating assessment and mitigation of earth-quake hazards. The weakening may be caused by active volcanoes, magma chambers, and overpressurized fluids in fault zones.

From Scientists to Society

Encouraging Application of Earthquake Research Results

By Jill Andrews

Californians thrive on diversity. We live in a place that offers constant challenge and frequent change. Our thrusting, majestic mountain ranges, deep green valleys, rugged deserts, lakes and rivers, and Pacific shores provide a natural setting for population with mixed cultures as varied and interesting as the landscape. For those of us who hate the boredom of predictable weather and flat lands interrupted by occasional low rolling prairies and towns that look the same, California is the only place to live.

In the early nineteenth century, hopeful settlers sought sudden fortune in the rich mines of the Sierra Nevada. Others seized opportunities to gain ultimate power in the urban and industrial growth and agricultural booms of the nineteenth and twentieth centuries. Still others have followed to join the quest to acquire notoriety and fame in southern California's entertainment industry.

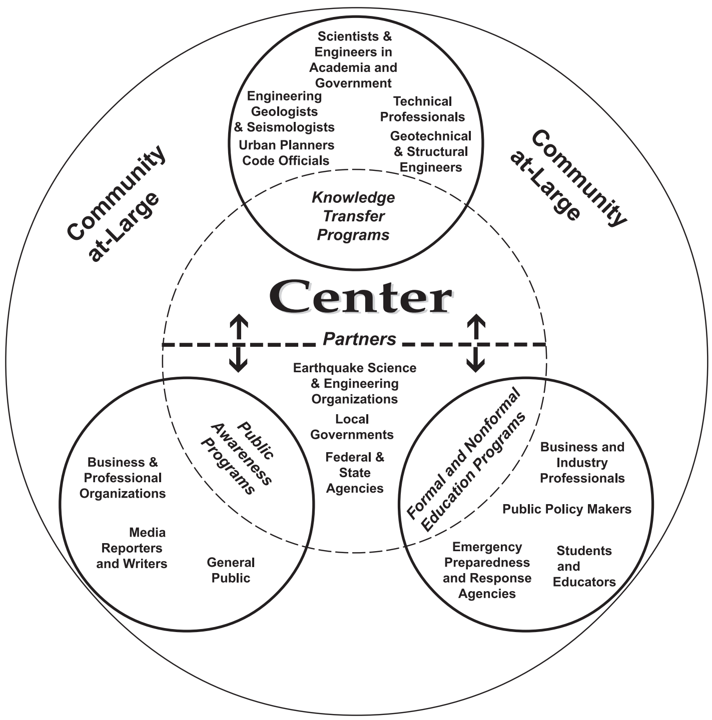
Despite its fast-growing, overcrowded cities, a taxed infrastructure, frequent Presidentially declared disasters and diminishing natural resources, Californians look to the next century with confidence that an entertainment-hungry, silicon-driven world will ensure a strong economy and plenty of opportunity.

As a native Californian, I join the boasting residents who are pleased to live in such an incredible place, but my disaster-related occupation constantly reminds me of a dark side to the challenges and changes posed by an beautiful but threatening geology. In fact, during the last decade, Californians have experienced the impacts of most known natural disasters: wildfires, floods, damaging wind, drought, volcanoes, and, of course, earthquakes.

If those aren't enough, we occasionally add human-made ingredients to the mix: toxic plumes, oil spills, power outages. And when our inner-city populations become bored with these, civil unrest breaks out.

Good News, Bad News

Given that shopping list of events, one would naturally think that we Californians would be experts on preparation and mitigation—especially related to earthquakes. The good news is that we generally enjoy the benefits of living in a state with a stable economy, a comparatively strong infrastructure and the most stringent building codes in the world. The bad news is that we are still very much like occupants of seismically active areas worldwide: our awareness of earthquake hazards, our vulnerability—especially in densely populated areas—is low.



The result of this bad news, says Kenneth A. Deutsch of the American Red Cross, will be a constant rise in social and economic costs related to disasters. A primary reason for these soaring costs, he adds, is the absence of proactive programs, policies, and actions to reduce the vulnerability of at-risk people and communities.

Questions, More Questions

During this International Decade for Natural Disaster Reduction, we've witnessed the development of some well-organized and highly visible earthquake-related public awareness, education, and knowledge transfer programs. Some of these are reaching large numbers of people. Through personal computers, the information superhighway, readily available network software and high-speed public communications systems, for example, we can access a vast global library of electronic information. We can use the Internet to search on the word "earthquake," and find hundreds of sites offering useful information, scientific databases, public hazard maps, and links to earthquake research organizations worldwide.

As the twenty-first century approaches, the booming "information age" phenomenon and the public's ever-increasing demand for knowledge will certainly drive cultural progress. Researchers who expect their results to be used need to be involved with all aspects of a new, knowledge-based economy. As university-industry collaborations mature, both can benefit from partnership: our economy's need for a constant supply of innovative ideas will be satisfied, and academic integrity will be protected.

Mutual benefit for academia and industry, however, is only one important reason for developing effective outreach methods. In the hazard mitigation arena, for example, knowledge can save time, money, and even lives. Earthquakes are inevitable, but the damage from earthquakes is not. The lesson of the last decade of earthquakes is that we can make our homes and cities safer. Local action to provide earthquake mitigation measures, however, depends largely on the awareness and education of everyone involved.

As earthquake scientists, engineers, emergency planners, preparation experts, responders, and outreach professionals, we should be asking ourselves whether our efforts are giving rise to *action*. We need to assess whether we are raising public consciousness to the degree necessary to effect positive changes in legislation and public policy.

> We are still very much like occupants of seismically active areas worldwide: our awareness of earthquake hazards is low, and our vulnerability is correspondingly high.

I have my own set of questions: What can outreach professionals do to facilitate use of existing and developing knowledge bases? How do we encourage better communication among researchers, practicing and consulting professionals, and public officials? What tools can be used to raise the level of awareness and encourage loss-reduction activities among all stakeholders in at-risk communities?

The *I*'s Have It

Southern California Earthquake Center's researchers grapple daily with these issues. They have a natural research laboratory in southern California with hundreds of active faults that may provide some answers. We do not claim to have discovered all the solutions, and we constantly seek ways to motivate vulnerable populations to take protective action.

Because SCEC is primarily a research consortium and is funded by the National Science Foundation and the U.S. Geological Survey, the approaches we use to transfer research results won't necessarily be a magic formula for others. But I believe that many can probably glean something useful from our collective experience.

We have discovered that to increase safety and awareness, we must improve the knowledge base of decision-makers, building and design professionals, educators, media reporters and writers, and the public. We have developed a mission to *promote earthquake loss reduction and lifelong learning by engaging the public at large in activities that focus on earthquake-related education, research-based technology development and transfer, and systemic reform.*

To accomplish our mission, we apply six action principles: Investigate, Identify, Initiate, Interact, Implement, and Iterate. The results of our efforts are just beginning to emerge: effective transfer of knowledge from researchers to the public; products that can be readily understood and applied; and new coalitions and partnerships that maximize resources and minimize duplication.

Investigate

Earthquake-related knowledge is primarily determined by the research community, but users' concerns and requirements are critical to facilitating application. For researchers to establish their goals and processes in the context of users' needs is a first step toward effective application of their research.

Before approaching the user community, however, researchers must self-investigate. It is particularly important to identify unique source strengths in light of the vision, goals, and research objectives. Consensus building among investigators and later, among researchers and end users, can be accomplished through the use of established methods such as the nominal group technique (NGT).

SCEC has used NGT in numerous workshops to conduct collective inquiry, encourage generation of individual ideas and judgments and effectively aggregate the results. We asked ourselves questions that helped us establish a clearly defined outreach plan: What is the vision? What are the goals? What are the research objectives? What key projects or products are research related? What are the significant or unique technical capabilities of the group? What successful activities or methods have been previously used to disseminate research results? What funding levels are required or recommended for past, present, and future projects? With the answers to these questions, we were ready to reach out to our end users. But how did we know who should use our research?

> Researchers who expect their results to be used need to be involved with all aspects of a new knowledge-based economy.

Identify

The next step was crucial. We had to identify "targeted" users with the capability to use our products. We learned that our research results needed to be packaged to "fit" various users. We selected a group of "working colleagues" (internal "champions") within our targeted user groups.

Our newly formed Research Utilization Council (RUC), as it is called, increased our credibility among users and promoted faster adoption of new information. We also recognized that we had to develop three distinct outreach efforts for these groups: public awareness programs for the general public and media reporters and writers; formal and nonformal education programs for students, teachers, emergency planners and responders, government officials, policymakers and insurers; and knowledge transfer programs for practicing design professionals, urban planners, code officials, and academicians.

Initiate

We next initiated a Yin and Moore-inspired "mutually influencing network" adapted to earthquake-related outreach (see figure). In a workshop setting, we presented to the RUC our overview of source strengths and capabilities. We asked them to help us create an outreach plan keeping in mind two goals: (1) to achieve consensus between users and among providers' leadership; and (2) to focus on simple and practical solutions so that we could increase use in a timely and cost effective way.

The council's advice was solicited on what products were needed by priority users, what communication and dissemination methods should be used, and what societal role SCEC should play. The results of the workshop set the stage for the next three steps: *interact, implement*, and *iterate.*

Interact

The best results occur when constant and direct communication occurs among the producers and users. We used the advice of our RUC as the basis for our strategic outreach work plan, but also resolved to continue interaction with them to stay current with their needs. Over the years, they have provided us with valuable feedback on the best methods of communication; identification of linkages or opportunities with end users; and help with establishing management policies that enhance our outreach efforts on a continuing basis. We learned from them that our research group management policies should:

- Ensure that research is disseminated and that products have useful application.
- Invite user participation within the research organization.
- Encourage principal investigators to improve technology transfer.
- Require principal investigators to involve users in each project.
- Assign higher priority to research proposals that include product development and dissemination efforts.
- Appropriate funding needed to support such an effort.
- Identify funding sources.
- Require that a utilization plan, or implementation strategy, be prepared for every project. These plans should describe the potential end uses of research results and also address how the results will be disseminated
- Develop performance measurements to evaluate the of research results. The measurements could be used as guides for funding research proposals, conducting post-research evaluations, and providing a feedback mechanism for a strategic science plan.

Implement

The number of ideas generated by the this process quickly overwhelmed us when we realized what it would take to implement them. We had to consider the feasibility of each project or product suggested, and account for time required (especially of researchers who already have full schedules), resources (can they be leveraged?), and capabilities.

We formed our activity plans in light of these considerations. We have learned that the following sample projects and activities encourage two-way communication while providing participants a variety of ways to stay in touch with the researchers and the results of their efforts:

- **Frequent science/engineering seminars.** Featuring state-of-the-art ideas, methods or hypotheses, these promote lively exchange among researchers. Although seminars primarily target scientists and engineers, we invite practicing professionals with expertise in applying the research.
- **Technical Briefs (4-8 pages).** Distribution of research results, in a form ready for application by professionals, should include recommendations for how to use the information in practice, as well as describe the limitations of the results.
- **Field studies.** In earthquake research, field studies are not only a necessity but an excellent means to transfer knowledge to other researchers and to end users. These activities take a great deal of time to plan, but if the effort is well documented and produced in a book or guide, they can be repeated with minimal effort.
- **Informational or Technical workshops or short courses.** These are an excellent tool to transfer scientific or technical information to end users with specific needs. Workshops are probably the single most effective tool in transferring dynamic knowledge. Workshops promote two-way communication and often stimulate innovative ideas for new approaches in solving problems. Short courses can be conducted in partnership with professional associations or academic organizations that can assist in developing course materials and provide other support.
- **Newsletters, special publications, World Wide Web sites.** These tools can significantly affect the community-at-large, provided the expertise and energy level of the knowledge transfer professional matches the resulting increase in public demand.
- **Agreements, alliances, partnerships, and links.** We have learned that successful linkages between researchers and users require participants who have knowledge of system processes, have a high tolerance for ambiguity, accept the high transaction costs associated with interdisciplinary activities, and are able to overcome communication problems by developing a common language. Partnerships should be based on collaborative behavior rather than merely being an exchange relationship; and must be flexible. We have also learned that each partner must contribute to bridging the gap between cultures to promote gains in knowledge transfer. Examples of opportunities for partnership in earthquake activities include probabilistic seismic hazard analysis, regional geologic mapping, active fault analysis, ground motion recording and archiving, and outreach and communication.

Iterate

An iterative process is embedded in any outreach program that implements tools such as seminars, workshops, field studies, and partnerships. Two-way communication is the basis of any successful outreach program. But brought to a higher level, that same outreach program can incorporate an iterative education process where both researchers and end users actively educate each other.

The results, we have learned, can be dramatic: refined and improved (and therefore usable) products; strengthened linkages and collaborative partnerships; and expanded opportunities. Our experience with the iterative process is that it also advances the concept of joint ownership among disparate groups. This in turn can lead to *consensus and implementation* of mutually identified priorities for earthquake hazard awareness, mitigation product development, information dissemination, and two-way communication.

Conclusion

Too much knowledge presently lies fallow, in part from a lack of promoting its active use. We at SCEC have experienced the benefits of our outreach principles. Because we have used these principles as a guide to successful outreach, we see daily evidence that we are fulfilling our mission. We now know that knowledge and use of new earthquake research results, especially by engineering design professionals, public policymakers, and government officials can promote public safety.

We also know that user-friendly information distributed widely and in understandable terms advances public understanding of the severity of an earthquake threat and probable consequences and can lead vulnerable populations to take protective measures. Finally, we know by our experience that community leaders and stakeholders can enhance their capacity to manage their own environment, resources, and natural hazards—even those unpredictable earthquakes—through better use of existing information and increased understanding.

References

Applied Technology Council Report ATC-35, pages 4, 19-20, "Requiring Utilization Plans to Enhance the Commitment of USGS Scientists to Utilization."

Atkinson, Richard C., Perspective on Research, High Stakes for Knowledge, Los Angeles Times, April 28, 1996.

Davis, James F., SCEC Site Review, August 27, 1996.

Delbecq, Andre L., Andrew H. Van de Van and David H. Gustafson, Group Techniques for Program Planning: A Guide to Nominal Group and Delphi Processes. Glenview, Illinois: Scott, Freeman and Company, 1975. Source for Figure 1: Johnson, Laurie, *Improving the Application of Earthquake Hazards Research in Southern California, An interim report on the research utilization planning process of the Southern California Earthquake Center,* March, 1995.

Deutsch, Kenneth A., Senior Mitigation Associate, Disaster Services, American Red Cross, personal communication, 19 August 1996.

Johnson, Laurie, *Improving the Application of Earthquake Hazards Research in Southern California, An interim report on the research utilization planning process of the Southern California Earthquake Center,* March 1995.

Jones, Lucile M., *Putting Down Roots in Earthquake Country.*

Mileti, Dennis, excerpt from the keynote speech delivered October 31, 1996, to the attendees of the City of Los Angeles, CDMG and SCEC sponsored "Exploring Seismic Zonation" Workshop.

Petak, William J., Bridging *the Gap Between Science and Practice*, USGS and IIPLR Cooperative Project on Earthquake Insurance Issues, September 24-25, 1996, Boston, MA.

Szanton, Peter, Not *Well Advised*, New York: Russell Sage Foundation, 1981.

Yin, R. and Moore, G., 1985, *The Utilization of Research: Lessons from the Natural Hazards Field*, Cosmos Corporation.

ESSTEP Field Trip

GIS/GPS Tour Included JPL, Caltech, San Andreas Fault

By Michael Forrest
Rio Hondo College

On July 15, the Earth and Space Science Technology Education Project (ESSTEP) conducted a field trip to the Jet Propulsion Laboratory, the GIS facility at Caltech, and the San Andreas fault. The purpose of this field trip was to combine hands-on experience with the use of equipment for monitoring and mapping faults.

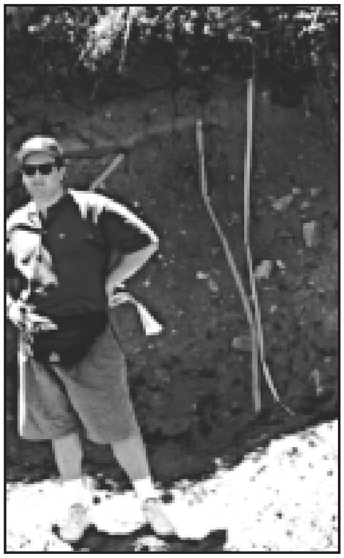
ESSTEP is a National Science Foundation project to train teams of professors and teachers to use GIS, GPS, and image processing. Participants included 25 educators from across the country and students from Rio Hondo College.

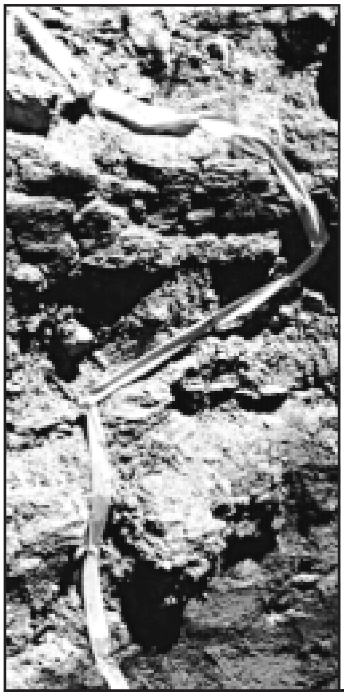
Dottie Stout of Cypress College, Ed Geary, and I led the bus trip. The first stop was the Benioff room of the Seismological Laboratory at Caltech. Hosts Andrea Donnellan and Bob Crippen presented an overview of current imaging, monitoring, and mapping technologies at JPL. We discussed the most recent plans to try to narrow down the area in which most of the massive deformation at the northern end of the Los Angeles basin is occurring and to identify the responsible faults.

Joe Franck took us on a tour of laboratory itself, followed by a visit to Kerry Sieh's image processing lab. Tony Soeller, the lab guru, spoke of things too complicated for some of us mere mortals to master. After the two-building, two-floor tour of Caltech, the group ate lunch while geology field stories and myths were traded during the bus ride to the San Andreas fault. Once at Wrightwood, Tom Fumal and two assistants led everyone to a stream-cut exposure two miles east of Park Avenue on Highway 2, the site of the fault.

It's astonishing and a bit terrifying to look at the thin contacts along the currently active rupture surface of the San Andreas and realize the phenomenal amount of energy that will inevitably be unleashed in the coming millennia. Farther up the road, on the second stop in Wrightwood, Tom showed us a San Andreas sag pond ringed by houses. We talked about the people living such geologically precarious lives inside these houses and shook our heads in wonder.

The last stop of the trip was in Lone Pine Canyon, where geologists on thousands of field trips during this last century have pointed to the west side of the valley and said, "Pacific Plate," and pointed to the east side and said, "North American Plate." On the way home, the group watched Dottie Stout's geology movie with pleasure and satisfaction. In fact, pleasure and satisfaction describe the entire field trip.





Above: Eric Bender stands in front of the San Andreas fault offset.

Left: the ribbon marks the trace of the San Andreas fault.

Below: participants used 3D glasses to view images during Robert Crippen's talk. (photo: Michael Forrest)

Photos: Michael Forrest

A TEACHABLE MOMENT...

by Sara Tekula

For Teachers in the Trenches

As a teacher, you know what a "teachable moment" is, right? That occasion in which circumstances or the students themselves create the perfect environment for learning to take place. One way to define teaching may be to think of it as creating and making use of teachable moments.

There is something similar in the world of earthquakes. Immediately after a damaging earthquake, in addition to the repairs to people and things, lots of attention is focused on the location of the earthquake, the reason for the earthquake, and the damage from the earthquake. Everyone, from average citizen to lawmaker, is hungry for information.

Earth scientists are eager for information of a different kind. They hunger and thirst for data. Without data from seismometers about the ground shaking or from visits to the site to gather measurements of the earth's movement, scientists are ignorant, uneducated.

An earthquake, then, is a teachable moment in many ways. For scientists, it's a chance to learn about how the Earth works. For engineers, it's a chance to learn how structures work. For lawmakers and politicians, it's a chance to see how laws and policies work. For teachers, it can be anything you want it to be.

Teachers—especially science teachers—need information that will inform students about what is happening around them and under their own feet as well as information about the mechanisms of the Earth, including earthquakes. And so we are launching this newsletter column.

We want to make sure you know how to keep your students both safe and aware. Ideally, students will walk away with the kind of information about their environment that will enable them to become teachers themselves. Through this column, I hope to present an opportunity for you and your concerns to be heard and to encourage decision-makers to consider the earth sciences as a subject area that is critical to the survival of our society. Those "trenches" you work in are sometimes so deep, you can't be heard. Consider this column your megaphone.

This column will focus on people, programs, and organizations promoting systemic change in the way that earth science is communicated to students as well as current and future teachers. I encourage you to write relevant pieces for this column. We at SCEC welcome partners who will join us in helping to build a permanent bridge between the communities of research scientists and teachers of science. The ultimate beneficiaries are the students who will be the scientists, teachers, and decision-makers of tomorrow.

Consider for a moment that everyone is a teacher. When we bring to light an issue that those around us haven't considered, we are causing them to think. When we tell a story about our own lives, others are given the chance to learn from our experience. Isn't that what teaching is all about? We've all agreed that talking is not teaching, and listening is not learning.

Psychologists who study how people learn tell us that the best learning takes place when we venture beyond the familiar. If we stay too comfortable, we are not placed in a position in which learning is necessary. Earthquakes are the perfect catalysts for learning—they remind us not to get too comfortable. In a way, an earthquake can be a teacher's best friend.

Those of you who make a lifetime commitment to teaching deserve the highest recognition. You hold the nation's future (its youth) in your hands. As educators, you can act as catalysts for change throughout the society. We at SCEC would like to do our part to facilitate that process, particularly through published projects and the Internet.

There are many Web-based aids for teachers interested in "raising the science bar" for their students. In the Online Resources area of this newsletter, you'll find a list of education-related Web sites that focus on the earth sciences. This list will grow, so please feel free to send me URLs for sites you like to use. The education pages on the SCEC Web site are under construction and these URLs will be linked to it. I envision this site eventually to be *your site*—filled with places you like to visit in the virtual landscape, including virtual field trips.

On behalf of the Southern California Earthquake Center, I applaud you for your dedication and action toward educational reform. After all, to quote the ancient saying, "To know the way and not practice is to be a soup ladle in the pot and never taste the soup." Keep tasting!

> The great end of education is to discipline rather than to furnish the mind; to train it to use of its own powers rather than to fill it with the accumulation of others. —TRYON EDWARDS

Sara Tekula is an outreach specialist for education on the SCEC staff. To contact her about SCEC's education programs or to contribute to this column, please call her at 213-740-2099 or email stekula@terra.usc.edu.

Education Web Sites for Teachers and Students

Compiled by Sara Tekula

Professional & Multidisciplinary

SCEC Education Pages
Semi-complete; check it out & give us feedback
http://www.scec.org/outreach

USGS Learning Web
A great site with many resources
http://www.usgs.gov/education

Multidisciplinary Center for Earthquake Engineering Research
See the former NCEER's Education Program
http://mceer.buffalo.edu

IRIS Education Outreach
Try the "Seismic Monitor"
www.iris.washington.edu/EandO

Pacific Earthquake Engineering Research (PEER)
A terrific education program
http://peer.berkeley.edu/html/education.html

American Association for the Advancement of Science
http://www.aaas.org/

American Geological Institute
Earth Science Education Programs
http://www.agiweb.org

In the Schools

Princeton Earth Physics Project (PEPP)
A program that puts seismometers in schools
http://lasker.princeton.edu/pepp.shtml

Purdue's "Seismology: Resources for Teachers"
Larry Braille's teaching tools are unparallelled
http://www.geo.purdue.edu/seismology_resources.html

YES Magazine's Parent and Teacher Resources
http://www.yesmag.bc.ca/pandt/pandt.html

National Association of Geoscience Teachers (NAGT)
http://oldsci.eiu.edu/geology/NAGT/NAGT.html

Science Education Association
http://science.coe.uwf.edu/

State of California Academic Standards Commission
http://www.ca.gov/goldstandards/

National Science Education Standards
http://www.nap.edu/readingroom/books/nses/html

California Department of Education
Teaching, Learning, and Technology
http://www.cde.ca.gov/pg2teach.html

Teach for America
Math and Science Initiative
http://www.teachforamerica.org

Program for the Advancement of Geoscience Education
http://www.page.ucar.edu

CSU L.A.'s Virtual Earthquake
http://vearthquake.calstatela.edu/edesktop/VirtApps/VirtualEarthQuake/VQuakeExecute.html

Earth and Space Science Technological Education Project
http://www.geosociety.org

Earth Science Online

Websurfer's Bi-weekly Earth Science Review
Every link you'd ever want
http://shell.rmi.net/~michaelg/weeksreviews.html

Global Positioning System (GPS) Overview
All you ever wanted to know about GPS
http://wwwhost.cc.utexas.edu:80/ftp/pub/grg/gcraft/notes/gps/gps.html

Information on "Plate Tectonics" CD-ROM by Tasa
Superb multi-level teaching tool with great graphics
www.swcp.com/~tasa

U. of Arizona's "Create Your Own Earthquake"
Don't try this at home
http://www.geo.arizona.edu/saso/Education/Plates

"This Dynamic Earth—The Story of Plate Tectonics"
Teach using USGS materials
http://pubs.usgs.gov/publications/text/dynamic.html

Denver Earth Science Project (DESP)
http://www.mines.edu/Outreach/Cont_Ed/desp.shtml

Lawrence Hall of Science
Science Education for Public Understanding Program
http://www.lhs.berkeley.edu/SEPUP

University Corporation for Atmospheric Research (UCAR)
Education Page
http://www.ucar.edu/ucargen/education/eduhome.html

Virtual Libraries

Virtual Earth Science Library
http://www.geo.ucalgary.ca/VL-EarthSciences.html

Virtual Geophysics Library
http://www-crewes.geo.ucalgary.ca/VL-Geophysics.html

Virtual Geotechnical Engineering Library
http://geotech.civen.okstate.edu/wwwVL/index.html

Virtual Field Trips/Exhibits

San Andreas Fault Field Trip
Bay Area region
http://sepwww.stanford.edu/oldsep/joe/fault_images/BayAreaSanAndreasFault.html

The Tech Museum of Innovation
Earthquake Exhibit
http://www.thetech.org/exhibits_events/online/quakes

Calendar

September

15-18—Western States Seismic Policy Council 20th Annual Conference, Pasadena, California. See WSSPC for more information: email wsspc@wsspc.org or web www.wsspc.org

21-25—International Association of Engineering Geologists & Canadian Geotechnical Society: 8th Congress of IAEG and the Environment. Vancouver, BC. Theme: A Global View of the Pacific Rim. Contact: congress@venuwest.com; or www.bchydro.bc.ca/iaeg/.

21-25—Earthquake Prognostics World Forum: Seismic Safety of Big Cities, Istanbul. Contact Dr. M. Hasan Boduroglu, Istanbul Technical University, bodurogl@sariyer.cc.itu.edu.tr. Home page: www.ins.itu.edu.tr/eaee/bigcities98.html.

October

15—Newsletter 4.3 articles and copy due to editor. Contact Ed Hensley, 916/353-9996.

17-20—SCEC Annual Meeting, Palm Springs, CA. Contact John McRaney, SCEC Administration, 213/740-5843.

22-23—Institute for Business & Home Safety 1998 Congress. Orlando, FL. Contact: Karen Gahagan at info@ibhs.org or see web: www.ibhs.org.

26-29—Geological Society of America Annual Meeting. Toronto, Canada. Contact: (800) 472-1988; meeting@geosociety.org; web: www.geosociety.org.

November

11-15—Fourth International Conference on Corporate Earthquake Programs, Shizuoka, Japan. Contact Steve Vukazich, conference chair, San Jose State University, 408/924-3858 or email vukazich@email.sjsu.edu.

December

7-10—American Geophysical Union Annual Meeting, San Francisco, California.

15—Newsletter 4.4 articles and copy due to editor. Contact Ed Hensley, 916/353-9996.

January 1999

10-14—Session planned for the World Archaeological Congress, Cape Town, South Africa. "Catastrophism, Natural Disasters, and Cultural Change." Info: www.uct.ac.za/depts/age/wac/

31—Deadline for registration and receipt of abstracts for INQUA symposium "Ice Sheets, Crustal Deformation and Seismicity: Neotectonics of Glaciated and Deglaciated Terrains," Durban, South Africa, August 3–11, 1999. Contact Iain Stewart (iain.stewart@brunel.ac.uk) or Jeanne Sauber (jeanne@steller.gsfc.nasa).

February 1999

15—Newsletter 5.1 articles and copy due to editor. Contact Ed Hensley, 916/353-9996.

WSSPC News

Nominations Invited for Excellence Awards

The Western States Seismic Policy Council is accepting applications for its Awards in Excellence program. The program recognizes achievement in different areas of earthquake mitigation, preparedness, and response. The awards are "a method for sharing model programs as well as recognizing the innovative efforts within the earthquake hazard-reduction community." For an application or more information, write WSSPC, 121 Second Street, 4th Floor, San Francisco, CA 94105 or email wsspc@wsspc.org.

In Palm Springs

SCEC 1998 Annual Meeting Set for October

The 1998 SCEC Annual Meeting will be held October 17–20 at the Riviera Resort and Racquet Club in Palm Springs, California. The 1996 annual meeting was held at the same location.

The agenda for the meeting will be prepared by the four SCEC directors with the help of Ralph Archuleta, Tom Rockwell, and Leon Knopoff. The agenda should be complete about the middle of August.

The deadline for submitting abstracts for posters is September 30, 1998. Please keep your abstract to 200-300 words. As requested by many of many participants, the time allocated for poster sessions will be increased this year. There will be no formal field trip.

All rooms (single, double, or more in the case of graduate students) will be $80 per night. Meals will be served banquet style as at past meetings. More details will be sent to all SCEC participants.

Anyone with questions should contact John McRaney, SCEC Administrative Director, at 213-740-5842 or mcraney@terra.usc.edu.

INQUA Hosts Ice Sheet Symposium

The International Union for Quaternary Research's Commission on Neotectonics is hosting the symposium "Ice Sheets, Crustal Deformation, and Seismicity: Neotectonics of Glaciated and Deglaciated Terrains" at the INQUA XV Congress in Durban, South Africa, August 3–11, 1999. The symposium will be jointly convened by Iain Stewart (Brunel, UK) and Jeanne Sauber (NASA, USA). The symposium will bring together Quaternary scientists, glaciologists, and geophysicists investigating the interaction between tectonic and glacial systems in various parts of the world. The deadline for registration and for receipt of abstracts is January 31, 1999. Applications for financial support should be submitted to INQUA by September 30, 1998. INQUA's web site is http://inqua.nlh.no/. Potential participants should contact Stewart (iain.stewart@brunel.ac.uk) or Sauber (jeanne @ steller.gsfc.nasa).

Earthquake Information Resources Online

SCEC on the Web

www.scec.org

SCEC Data Center

http://www.scecdc.scec.org/
SCEC Data Center home page

http://www.scecdc.scec.org/recenteqs
Recent earthquake activity in northern and southern Calif. Maps and earthquake lists are interactive and updated at the time of an event

http://www.trinet.org/eqreports
Southern California Seismic Network weekly earthquake reports

http://scec.gps.caltech.edu/ftp/ca.earthquakes
SCSN weekly & monthly earthquake reports (archives to Jan. 1993)

http://www.scecdc.scec.org/seismocam/
Caltech/USGS Seismocam: waveform displays of data 30-seconds-old earthquakes in southern California: includes aftershock maps, animations of aftershock sequences and rupture models, a clickable map of historic southern California earthquakes, and Putting Down Roots in Earthquake Country (online book)

http://www.scecdc.scec.org/eqsocal.html
Main page

http://www.scecdc.scec.org/clickmap.html
Southern California clickable earthquake map

http://www.scecdc.scec.org/labasin.html
http://www.scecdc.scec.org/easocal.html
Los Angeles basin clickable earthquake map

http://www.scecdc.scec.org/eqsocal.html
Earthquakes in southern California

http://www.scecdc.scec.org/bymonth.html
Time-lapse animations of southern California seismic activity

http://scec.gps.caltech.edu/cgi-bin/finger?quake
"Finger Quake" ftp (updated frequently)

http://www.scecdc.scec.org/faultmap.html
Southern California fault map

http://www.scecdc.scec.org/lafault.html
Faults of Los Angeles

http://www.scecdc.scec.org/larse.html
LARSE home page

http://scecdc.gps.caltech.edu/catalog-search.html
Interactive SCSN seismicity catalog search page

http://www.scecdc.scec.org/eqcountry.html
Putting Down Roots in Earthquake Country (online book)

USGS Web Sites

http://www.usgs.gov
General USGS site

http://gldss7.cr.usgs.gov/
National Earthquake Information Center

http://geology.usgs.gov/quake.html
Earthquake Information

http://quake.wr.usgs.gov/
USGS Menlo Park

http://www-socal.wr.usgs.gov
USGS Pasadena

http://geohazards.cr.usgs.gov/northridge/
USGS Response to an Urban Earthquake — Northridge '94

http://www-socal.wr.usgs.gov/north
Summary of work of USGS after Northridge '94, including datasets

http://www-socal.wr.usgs.gov/lisa/NETBULLS
Southern California Seismic Network (bulletins)

http://www.seismo.unr.edu
Nevada Seismological Laboratory

Work by two SCEC-funded researchers, John Anderson and Steve Wesnousky. Contains lists, maps, and seismogram data from recent earthquakes, including searchable earthquake catalogs and more

http://erp-web.er.usgs.gov/
Recent USGS NEHRP Research Contracts

USGS email addresses

neic@usgs.gov
National Earthquake Information Center

ngic@usgs.gov
National Geomagnetic Information Center

nlic@usgs.gov
National Landslide Information Center

Paleoseismology

http://inqua.nlh.no/commpl/palseism.html
The INQUA Subcommission on Paleoseismicity: content list and authors for the special issue of journal of geodynamics arising from the INQUA Berlin 1995 symposium on paleoseismicity.

Active Tectonics

http://www-geology.ucdavis.edu/~GEL214/
University of California, Davis—Active Tectonics
- Lecture notes ("Contents")
- Problem sets ("Problems") for this course
- WWW links ("Links") of interest to students and researchers
- References

GIS Web Sites

http://warehouse.geoplace.com/
Bibliography of GIS & environmental applications:

http://pasture.ecn.purdue.edu/~engelb/
Bernie Engel, professor of agricultural engineering: soil and water conservation, environmental issues, systems engineeering

http://www.lib.berkeley.edu/cgi-bin/print_hit_bold.pl/UCBGIS/
UCB GIS Task Force integrates GIS activities with other resources

http://www.nwi.fws.gov/thinktank.html
GIS think tank on problems of digital mapping for NWI data

http://fgdc.er.usgs.gov/linkpub.html
List of FTP directories for federal Geographic Data Committee

Continued on next page . . .

Online Resources *continued*

http://mis.ucd.ie/staff/pkeenan/gis_as_a_dss.html
Paper on how to use a GIS as a DSS generator

http://spsosun.gsfc.nasa.gov/EOSDIS_services.html
A spectrum of services, from casual user to researcher

http://www.ggrweb.com/
Information technologies, GIS, GPS, & remote sensing industries

Geodetic Information

http://lox.ucsd.edu
This site is the IGPP & Scripps Orbit and Permanent Array Center (SOPAC) and features global (IGS) and regional (SCIGN) continuous GPS archive, SCIGN maps, time series, and site velocities.

GMT

http://quake.ucsb.edu
Make shaded relief maps with GMT. Catalog of maps by Geoffrey Ely at ICS/UCSB. DEM for southern California. Click on "Mapping" and then "Geoff's Map Catalog."

Preparedness, Disaster Management

http://www.best.com/~trbu/oes/
California Governor's Office of Emergency Services: information on Earthquake Preparedness Month campaign

http://www.seismic.ca.gov/ssccatr.htm
California's earthquake hazard mitigation plan

http://kfwb.com/cucamong.html
KFWB Webservice exclusive: trenching the Cucamonga fault:

http://www.highways.com/lasd-eob/
The Los Angeles Sheriff's Emergency Operations Bureau

http://www.kfwb.com/epc/epcfact.html
Emergency Preparedness Commission for L.A. City & County

http://www.johnmartin.com/eqprep.htm
John A. Martin & Associates

http://www.eerc.berkeley.edu/
Earthquake Engineering Research Center offers extensive, searchable database of abstracts, reports, and other resources. New: "Lessons from Loma Prieta,"with papers, images, and data.

Earthquake Information Sites

http://www.eqnet.org/
EQNET

http://www-socal.wr.usgs.gov/seismolinks.html
Comperhensive list of links to seismology, geology, vulcanology

http://www.geophys.washington.edu/seismosurfing.html
Clearinghouse of research data & informmation

http://www.trinet.org/
Trinet—the seismic system for southern California

http://mceer.eng.buffalo.edu/enews
Express news, customizable service that delivers earthquake/ hazards information selected from MCEER Information Service

http://www.civeng.carleton.ca/cgi-bin/quakes
Recent quakes (with a good map viewer)

http://www.crustal.ucsb.edu/scec/webquakes/
Up-to-the-minute southern California earthquake map—latest 500 earthquake locations. Java-enabled browsers only.

http://kfwb.com/eqpage.html
KFWB Quake Page (by Jack Popejoy)

http://smdb.crustal.ucsb.edu/
A relational database strong motion recordings.

http://www.consrv.ca.gov/dmg/shezp/psha0.html
Probabilistic Seismic Hazard Map, California

http://www.abag.ca.gov/bayarea/eqmaps/liquefac/bayaliqs.gif
Bay Area hazard map

http://www.wsspc.org
Western States Seismic Safety Policy Council site, an overall earthquake safety information source.

http://www.seismic.ca.gov/sscleg.htm
Current state and federal bills being tracked by the Commission)

http://www.seismic.ca.gov/sscsigeq.htm
Seismic Safety Commission—significant damaging earthquakes

http://shell.rmi.net/~michaelg/weeksreview.html
Biweekly earth science review

Internet Discussion Groups

wsspc-l@nisee.ce.Berkeley.edu
Western States Seismic Policy Council discussion group

eq-geo-net@gsjtmws8.gsj.go.jp
Paleoseismic ListServe

gvn@volcano.si.edu
Global Volcanism Network

quaternary@morgan.ucs.mun.ca
Research in quaternary science

seismd-l@bingvmb.bitnet
Seismological discussion list (SEISMD-L)

quake-l@listserv.nodak.edu
Earthquake discussion list

Education

http://www.scec.org/outreach
SCEC Education Pages: semi-complete; check it out & give us feedback

http://www.usgs.gov/education
USGS Learning Web:A great site with many resources

http://mceer.buffalo.edu
MCEER Education Program

www.iris.washington.edu/EandO
IRIS Education Outreach: Try the "Seismic Monitor"

http://peer.berkeley.edu/html/education.html
Pacific Earthquake Engineering Research: terrific ed. program

http://www.aaas.org/
American Association for the Advancement of Science

http://www.agiweb.org
American Geological Institute

SCEC Quarterly Newsletter

a component of the Center's Outreach Program

For more information on
the SCEC Outreach Program,
see the Outreach Web page at
WWW.SCEC.ORG
OR contact:

Jill Andrews, Outreach Director
213/740-3459 or jandrews@terra.usc.edu

Mark Benthien, Outreach Specialist
213/740-0323 or benthien@terra.usc.edu
(general information, publications, WWW)

Sara Tekula, Outreach Specialist
213/740-2099 or stekula@terra.usc.edu
(education and community outreach)

To Subscribe: One year's subscription costs $25.00. Please make payment by check, money order, or purchase order payable to "University of Southern California/SCEC." Do not send currency. Price includes postage within the U.S. Overseas airmail costs or special courier services will be billed. SCEC scientists, students, and affiliated agencies receive this newsletter free of charge.

Mail your name, mailing address, phone number, email, and check for $25 to:

Southern California Earthquake Center
University of Southern California
Los Angeles, CA 90089-0742

Subscribers: Check your mailing label for the last issue of your current subscription. If "free" is listed, you will continue to receive the newsletter indefinitely. If any changes need to be made to your address, please call 213-740-5843 or email scecinfo@usc.edu

Newsletter on the Web: WWW.SCEC.ORG/NEWS

Current issues can be accessed only by current recipients of the newsletter. Back issues are accessible without a password. The online newsletter will feature active links to other web pages with related information. To access the current issue online, enter the following when prompted:

username: scecnewsletter
login: issue42

Have questions? Call, fax, or email:

Tel: 213/740-1560
Fax: 213/740-0011; Email: SCECinfo@usc.edu

Southern California Earthquake Center

A National Science Foundation
National Science and Technology Center
in partnership with
the United States Geological Survey

Administration

Thomas Henyey
Center Director

David Jackson
Science Director

John McRaney
Director of Administration

Jill Andrews
Outreach Director

Board of Directors

David Jackson, Chairman
University of California, Los Angeles

Bernard Minster, Vice Chairman
Scripps Institute of Oceanography
University of California, San Diego

John Anderson
University Of Nevada, Reno

Ralph Archuleta
University of California, Santa Barbara

Robert Clayton
California Institute of Technology

James Dolan
University of Southern California

James Mori
United States Geological Survey

Thomas Rockwell
San Diego State University

Leonardo Seeber
Lamont-Doherty Earth Observatory

Inside This Issue

Articles

Departments

SCEC Quarterly Newsletter

SCEC Quarterly Newsletter is published quarterly by the Southern California Earthquake Center, University of Southern California, Los Angeles, CA 90089-0742, USA, telephone 213/740-1560 or 213/740-5843, fax 213/740-0011, email: SCECinfo@usc.edu.

Producer: Jill Andrews
Editor: Ed Hensley
Feature writer: Michael Forrest

Writing: Jill Andrews, Mark Benthien, Thomas Henyey, Susan Hough, Monica Kohler, Karl Mueller, Charlie Sammis, Ross Stein, Sara Tekula

Photography: Mark Benthien, Michael Forrest, Tom Henyey, Monica Kohler, Ross Stein, Sara Tekula

Editorial assistant: Linda Townsdin

Seeber Photograph:
Courtesy Lamont-Doherty Earth Observatory

Column Illustrations:
Jim Hensley

Cover:
Relief map: southern L.A. basin, including San Joaquin Hills

FOR SUBSCRIPTION INFORMATION—SEE PAGE 39

Southern California Earthquake Center
University of Southern California
Los Angeles, CA 90089-0742

ADDRESS CORRECTION REQUESTED