Quarterly Newsletter
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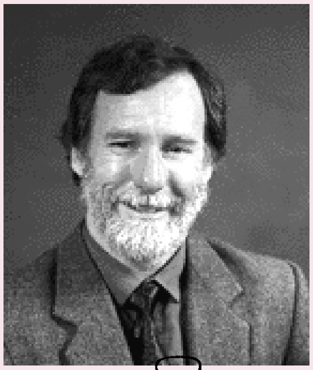
Southern California Earthquake Center

From the Center Directors

Thomas H. Henyey

Center Director



David D. Jackson

Science Director

EarthScope—a New and Exciting Initiative

By Tom Henyey

The Earth Sciences Division (EAR) at the National Science Foundation (NSF) is working with the scientific community to orchestrate a new and potentially exciting scientific initiative called EarthScope. EarthScope would consist of large arrays of state-of-the-art seismic and geodetic instrumentation, much of it focused on active tectonics of the Pacific/Juan de Fuca-North American plate boundary of the western U.S. A deep earth observatory along the San Andreas fault at Parkfield also would be part of EarthScope.

> *We would be in a position to detect precursory strain transients that may prove practical for forecasting earthquakes and volcanic eruptions.*

SCEC is one of several major NSF-funded programs helping EAR shepherd the initiative through the Foundation's administrative structure. If funded over the next several years, these new facilities would be an important resource for a future earthquake center and for achieving the goal of improving our understanding of the earthquake process.

Particularly relevant to earthquake physics is the geodetic (strain) component of the initiative, referred to as the Plate Boundary Observatory (PBO). The PBO is expected to consist of a mix of GPS instrumentation, strainmeters, and InSAR images that can be used to address such questions as:

- How is deformation accommodated within a plate boundary zone?
- What controls the spatial characteristics of plate boundary deformation?
- What controls temporal variations in a plate boundary?
- Are there deformation transients that propagate within the plate boundary zone?
- What is the relationship between vertical and horizontal tectonics?
- How does plate motion ultimately produce an earthquake?
- How do faults and earthquakes interact with one another in time and space?

The PBO would measure deformation over a broad spectrum of spatial and temporal scales and provide sufficient resolution to constrain any transients associated with short-wavelength phenomena such as earthquakes and magmatic activity. A close integration of seismometers, GPS, strainmeters, and InSAR is necessary to provide uniform strain-rate sensitivity at plate-motion strain rates and across the temporal band from several Hertz to a decade.

> *The plate boundary observatory is expected to consist of a mix of GPS instrumentation, strainmeters, and InSAR images.*

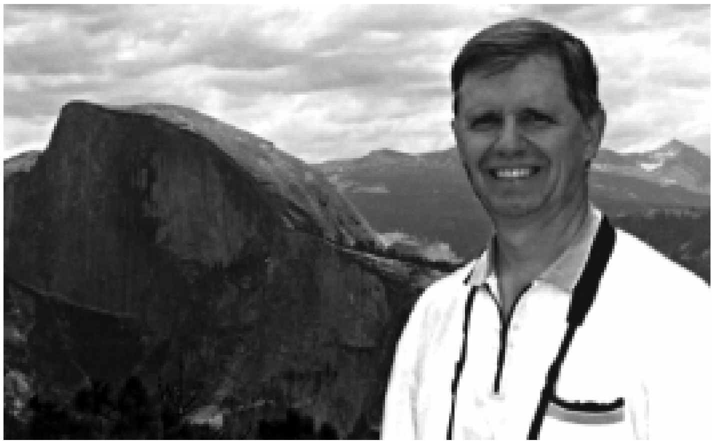
Thus, the establishment of a fully capable PBO will require progress in four areas: 1) a more effective integration of strainmeters and GPS for a truly broadband observatory; 2) the densification of geodetic and seismic instrumentation along the northern San Andreas, and perhaps other faults, for increased spatial resolution; 3) the linking of the major earthquake-producing zones to cover the seismogenic part of the plate boundary; and 4) increasing the access to InSAR data.

While the main focus of the PBO would be to gain a basic understanding of plate boundary processes, it also would provide information of practical value. In particular, we would be in a position to detect precursory strain transients, should they occur, that may prove practical for forecasting earthquakes and volcanic eruptions. Let's hope EarthScope becomes a reality—it's our opportunity to add significant new resources to the entire earth sciences community. ■

Editor's Note: As this issue was prepared, Bernard Minster was announced as the new Acting Science Director for SCEC. Please see page 35 for the administrative structure as of August 1, 1999.

John Anderson

Interviewed by Jill Andrews



John Anderson, director of the Seismological Laboratory at the University of Nevada at Reno and member of the SCEC board of directors, is interviewed here about his work in strong motion seismology, especially in the context of the SCEC mission.

SCEC: You and your group appear to be in a "transition zone" between basic research and tangible products—in other words, you are trying to find results that are immediately useful. What have you found so far, and who will use the results of your work?

JA: First, I think it is not as far from basic seismic research as it may appear. I'm thinking of a vision for strong motion seismology given in 1980 by Keiiti Aki (SCEC director, 1991–1996) in an address when he was the outgoing president of the Seismological Society of America. He said: "Our goal is to compute seismic motion expected at a specific site of an engineered structure when the fault mapped by geologists breaks." So "synthetic" seismograms are the goal. We want them to be so realistic that engineers can use them. But we also want them to be based on sound understanding of the physics of the earthquake process so that they will be reliable.

Nearly every task SCEC identified for southern California ought to be done in Nevada, in Utah, near New Madrid and every other seismic zone in the U.S.

SCEC: How can this be achieved?

JA: We have to bring in source physics, wave propagation, and scattering caused by the complexity of the Earth. At the least, we have to take what others have learned and incorporate it into our models. On the other hand, one can hope that our research; i.e., the constraints on the physical processes needed to successfully predict strong motions, will lead to some increased understanding of the physics.

SCEC: Let's focus on your work as it relates to the Southern California Earthquake Center, specifically, your work on the Phase III Report (need official name for this report). How would you define the term "strong motion seismologist" to someone who doesn't have a background in geophysics?

JA: I'd define strong motion as earthquake motions that are strong enough to feel. Strong motion seismologists might also be recognized by one type of instrument that is essential for their research. They must have accelerographs, which are distinguished from the instruments used by most other seismologists in that they stay on scale in even the strongest shaking but can't detect weak earthquakes that are easily observed using higher gain instruments. Twenty years ago, before the digital revolution in instrumentation, the weakest signals these instruments could record were just about at the threshold of human detection. Now, the digital accelerographs can record local earthquakes below magnitude 3, which is way below what a person can normally feel. So accelerograph data is getting more interesting to network seismology, and the distinction between strong motion seismologists and others is getting blurred. Still, the original focus of strong motion seismology is to understand ground motions that are strong enough to cause damage. That's still true.

SCEC: How completely has the digital accelerograph replaced the old analog instrument? Do you still use both?

JA: The most common analog strong motion accelerograph in the world, the Kinemetrics SMA-1, was discontinued many years ago, but there are still large numbers of them out in the field. The data they produce is very good data, but it's less convenient to use because they record strong motions on film, which has to be retrieved and then digitized. This is very time consuming. The advantage of digital instruments is that the data are available immediately, and the resolution is much better. On analog, one can resolve differences in acceleration of maybe 1,000th of the acceleration of gravity. With new digital instruments, there's about a 100-fold improvement.

SCEC: How does that affect your work?

JA: With a really strong earthquake, you're well above the "noise" level over a certain frequency band; with digital instruments, you are well above the noise level for a wider range of frequencies. So you have much more accurate data for both lower and higher frequencies than with the old instruments. Also, the same instruments record smaller earthquakes, which can be used as empirical Green's functions for some of our research.

> *Major earthquakes occur rarely, and every one is either an opportunity or a missed opportunity to learn more.*

SCEC: Let's shift back to the field of strong motion seismology. According to your colleague and coordinator of the SCEC Phase III report (Ned Field), logic dictates that strong motion seismology should be a well-funded branch of seismology. Is there enough support provided by government agencies, or could there be more?

JA: More support could be used to accelerate both scientific discovery and the development of practical results. In this regard, I'm not so sure strong motion seismology has either better or worse funding than many other fields of seismology. For instance, most of our regional seismic networks are seriously under-funded. Research on data collected by those networks is also under-funded.

SCEC: Why?

JA: There is the usual cliché answer: that without more frequent disasters, the public and Congress tend to forget about earthquake hazards, and seismology drops to a lower priority on the political agenda. That may contribute to the problem, but I don't think it is the complete answer. Another factor may be an apparent weakness in our case for relevance. The building code is the only place where most people have to spend money on seismic hazards. These codes give "cookbook" answers to seismic design for most structures, and our engineers are probably correct in their assertion that most structures are designed well for life safety. With that apparent weakness, how should we convince the general public and Congress that understanding more about the earthquake hazard is essential for making better decisions on a daily basis, thus reducing the future risk? Of course, there are existing programs that demonstrate the relevance of this kind of research—TriNet is one example. TriNet *[Ed. note: the USGS-Caltech-California Division of Mines & Geology consortium to upgrade California's seismic networks to digital]* gives immediate information for emergency response and to satisfy the broad curiosity about earthquakes; those are

Professional Highlights

John Anderson

Education
Ph.D., geophysics, Columbia University
B. S., physics, Michigan State University

Professional
SCEC Board of Directors
University of Nevada, Reno–Mackay School of Mines
Professor of Geophysics, Department of Geological Sciences
Seismological Laboratory Director

Research Interests
John Anderson's research in strong motion seismology has taken him to Mexico, Japan, Turkey—and yes, even exotic southern California. He's hosted visiting scholars from India, Iran, China, and Korea, and looks forward to traveling to those places. His research interests span all aspects of engineering seismology, including applications of geological and seismological information to estimate seismicity and seismic hazards; recording strong ground motions; understanding the physics of near-source ground motions; and applications to engineering problems.

Selected Publications
Anderson, J. G., and S. Hough, A model for the shape of the Fourier amplitude spectrum of acceleration at high frequencies: *Bull. Seism. Soc. Am.* 74:1969-1994, 1984.

Anderson, J. G., P. Bodin, J. Brune, J. Prince, S. Singh, R. Quaas, M. Onate, and E. Mena, Strong ground motion and source mechanism of the Mexico earthquake of Sept. 19, 1985, *Science* 233:1043-1049, 1986.

Zeng, Y., J. G. Anderson, and G. Yu, A composite source model for computing realistic synthetic strong ground motions, *Geophysical Research Letters* 21:725-728, 1994.

Zeng, Y., J. G. Anderson, and F. Su, Subevent rake and random scattering effects in realistic strong ground motion simulation, *Geophysical Research Letters* 22:17-20, 1995.

Zeng, Y., and J. G. Anderson, A composite source model of the 1994 Northridge earthquake using genetic algorithms, *Bull. Seism. Soc. Am.* 86:S71-S83, 1996.

Anderson, J. G., and G. Yu, Predictability of strong motions from the Northridge, California, earthquake, *Bull. Seism. Soc. Am.* 86:S100-S114, 1996.

Anderson, J. G., Seismic energy and stress drop parameters for a composite source model, *Bull. Seism. Soc. Am.* 87:85-96, 1997.

Ni, S.-D., R. Siddharthan, and J. G. Anderson, Characteristics of nonlinear response of deep saturated soil deposits, *Bull. Seism. Soc. Am.* 87:342-355, 1997.

Lee, Y., Y. Zeng, and J. G. Anderson, A simple strategy to examine the sources of errors in attenuation relations, *Bull. Seism. Soc. Am.* 88:291-296, 1998.

Su, Feng, J. G. Anderson, and Y. Zeng, Study of weak and strong ground motion including nonlinearity from the Northridge, California, earthquake sequence, *Bull. Seism. Soc. Am.* 88:1411-1425, 1998.

Anderson, J. G., and J. N. Brune, Probabilistic seismic hazard analysis without the ergodic assumption, *Seismological Research Letters* 70:19-28, 1999.

strong selling points for the general public. Another example is SCEC's outreach program, which is excellent. It does a great job of sharing our excitement about our scientific discoveries. If we as a seismological community did as well in outreach in the rest of the nation, maybe the national support for seismology would be much better.

SCEC: How do you resolve this "apparent weakness" in the case for relevance?

JA: First, I think there are really large uncertainties in the inputs to even the newest code guidelines and/or requirements, such as the new probabilistic seismic hazard maps produced by the USGS and the California State Department of Conservation's Division of Mines and Geology.

SCEC: Can these uncertainties be resolved over time? What can scientists do to reduce the large uncertainties? Or can we learn to work with what we have and concentrate on mitigation?

JA: My opinion is that SCEC is doing exactly what needs to be done to reduce uncertainties. We are conducting research that ultimately will benefit society, because in the long run reducing the uncertainties will be more economical. The latest SCEC RFP is a masterpiece. *[Ed. note: every year the SCEC board of directors develops a research plan that is circulated to SCEC researchers as a request for proposals, inviting them to submit a proposal describing what they would like to do to help achieve that plan in the coming year.]* Nearly every task SCEC identified for southern California ought to be done in Nevada, in Utah, near New Madrid and every other seismic zone in the U.S. Every task would make a significant contribution to understanding the earthquake threat in those areas, also

SCEC: Let's get back to your group's contributions.

JA: For the past few years, primarily with SCEC support, we've been developing what we call a "composite source model" to predict strong motions. The approach is entirely synthetic. We don't use empirical Green's functions or empirical earthquake source functions. Our synthetic Green's functions include wave propagation in an attenuating Earth, and we've added in scattering calibrated from small earthquakes. The composite source seems to have the right amount of complexity, and the parameters can all be correlated with macroscopic variables like seismic moment and energy. We've tested it against the observations for the major earthquakes in southern California, and it seems to perform reasonably. The model has a random part to it, but we've shown that the source of several earthquakes, including the Northridge earthquake, can be described with a specific realization of the model. We're still working on improving it. And it is being used in some applications in private industry. One of the latest phenomena that we've found necessary to include in the model is nonlinearity in the soil response. When we make a model that is successful for all the distant stations it significantly overpredicts the ground motions at the closest sites. Then when we apply a more-or-less standard correction to those nearby sites for expected nonlinear stress-strain relationship in the alluvium below those sites, the predictions come in much closer to the observations.

> *SCEC has given the seismological community a transportable model for attacking the scientific and social issues associated with earthquakes.*

More About the SCEC Phase III Report

Several years ago SCEC embarked on a multidisciplinary effort to determine how and whether seismic hazard analysis can be improved by accounting for site effects (the propensity for certain sites to shake harder than others).

As of 1997, the results of these studies had been combined into an engineering-style report (called the SCEC Phase III Report), which was reviewed by an independent team of experts. They agreed that the report contained many important findings but that it needed some streamlining.

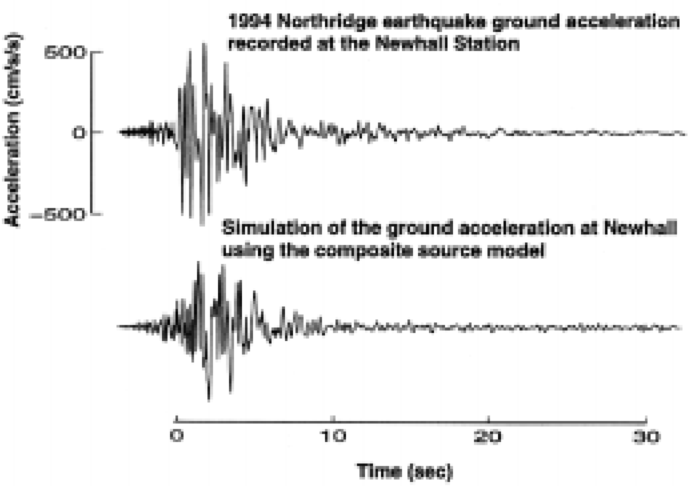
After some delay it became apparent this would not happen without a full-time editor. One now exists—Edward (Ned) Field—and the report is well on its way to completion.

Rather than producing a document primarily aimed at engineers, Phase III will be published as a collection of scientific papers in a special issue of the *Bulletin of the Seismological Society of America* (pending acceptance). Issues that were addressed in the earlier version relating to the characterization of seismic sources (updating Phase II) and to computing synthetic seismograms have been omitted. The report will now focus exclusively on how, and whether, probabilistic seismic hazard analysis (PSHA) in southern Californiacan be improved by accounting for site effects.

Field and colleagues made a diligent search for any characteristics that systematically predispose a site to greater (or lower) levels of ground shaking. They found some significant attributes, such as surface geology and depth to bedrock in sedimentary basins that indeed correlate with observed amplification factors. They also tested which of several attenuation relations are most consistent with southern California data and with theoretical considerations where data are lacking. They are currently quantifying the influence of these factors on PSHA.

A preliminary conclusion is that except in some specific circumstances, only modest improvements can be made by accounting for site effects. However, even modest improvements may be significant in terms of the implied seismic hazard.

SCEC: To improve seismic design and probabilistic seismic hazard assessment, you and your colleagues conduct regression analyses to develop empirical ground motion models, which predict ground motion characteristics as a function of magnitude and distance. Can you explain what is involved with doing regression analyses, define in simple terms what an empirical ground motion model is, and explain why prediction of ground motion characteristics as a function of magnitude and distance is important to design professionals?



An observed strong motion accelerogram compared to a synthetic one. (Prepared by Y. Zeng, 1999, based on work in progress.)

JA: There are several ways to predict ground motions. The standard engineering approach is with a ground motion prediction equation. This approach seeks to predict some ground motion parameter, such as peak acceleration, as a function of several variables, which have to include magnitude and distance. Generally these equations add additional terms that seek to characterize the site conditions in some way also.

The first step of the process includes making up an ad-hoc form for the equation—something that you hope will capture the average trends. The second step uses regression analysis to estimate the unknown coefficients in these equations. This approach generally predicts ground motions to within a multiplicative factor of about two. In one of our Phase III contributions, I examined the physics to try to make some general statements about the expected characteristics of these prediction equations, and we also evaluated some of the existing equations for use in southern California.

I have to admit, though, that I'm not particularly enthusiastic about developing new ground motion prediction equations. The first problem with these is that there is little to be learned about the physics of earthquakes or wave propagation in the process. The second is that the process is endlessly complicated. Strong ground motions are extremely complicated time series. Anyone who hopes to characterize them adequately with a few parameters is doomed to failure. The ground motion prediction equations may be developed for a dozen or so characteristics of a suite of seismograms. But that is not enough. Also, every time another earthquake happens you have to carry out a new regression, and every time you use the prediction equation you have to worry about whether it is appropriate for the region. That's why the type of "ground motion prediction" that we are mainly working on is synthetic seismograms.

There is far more information in synthetic seismograms than in any prediction equation. If we can generate a reliable synthetic seismogram, then the engineer can determine any parameter he wants from the synthetic seismogram. We don't need to worry about the whether the prediction equations that we used are correct. Instead, we worry about whether the source model and the earth structure model that we used are correct. Ultimately, this will be much simpler than ground motion prediction equations.

Supporting more strong motion instruments at major faults around the world is expensive, but we stand to learn the answers to some fundamental questions sooner.

SCEC: What can scientists do to help design professionals incorporate research results?

JA: That's a difficult question because "design professionals" includes a wide range of activities—an architect planning a one-story house, on one hand, or, at the other extreme, structural engineers who design skyscrapers; the latter are people who are usually talking to strong motion seismologists in the first place. They would be the people more likely to ask for seismograms to test their designs.

SCEC: Let's talk about the progress of strong motion seismology in relation to better engineering design on a worldwide basis. Are researchers in your field making less rapid progress than if there were more funds for the field?

JA: The answer is yes. Major earthquakes occur rarely, and every one is either an opportunity or a missed opportunity to learn more. There are a lot of questions about the earthquake source that will only be finally answered with strong-motion observations. An example would be the question of how long the San Andreas fault takes to slip in a major earthquake. One thing we know is that strong motions are highly variable over space, and the motion field is seriously undersampled. To get a description of the strong motion field without spatial aliasing, we need many more strong motion instruments than there are at present. Yokohama is the only city in the world that is currently operating a strong motion network approaching a sufficient density to thoroughly document the strong motion wavefield at the frequencies that affect structures. They have 150 accelerographs in an area of 433 km^2, or about one instrument every 3 km^2. Tokyo is working on an even denser network. Mexico City's network is also very good. Its density is much lower, but the dominant motions are low frequency waves, so you can get start to get a good picture of what is happening. With the complexity of seismic waves in basins, this empirical approach may be the best way to understand and prepare for local variations in the motions.

Is it fundamental science? Conceptually, if you have a good enough description of the velocity model and a big enough, fast enough computer, maybe the spatial variation in the motions could be predicted. I think that density of stations would be approaching a level where a new challenge could be tackled, though, namely to invert the complete observed wavefield to derive the structure of the basin.

SCEC: You mentioned Mexico. Describe some of your research there.

JA: I've been working in Mexico since 1980. Jim Brune (UNR) and I installed a strong motion network in Guerrero *[Ed. note: the Guerrero Accelerograph Array is near Acapulco, which is above the subduction zone along the Pacific coast]*. In this zone, we believe that there are major earthquake occurrences (M 7.8-8 or greater) quite frequently, about once every 50 years or less. We installed 30 strong motion instruments on rock sites in the vicinity of Guerrero Gap. Shortly after we started the project, the September 19, 1985, earthquake occurred (M 8.1). The records we got on the Pacific coast are still almost unique due to their location directly above the fault in a M 8+ earthquake. It turned out that the Guerrero data was critical for understanding the ground motions in Mexico City, which is 400 km from the fault. The really interesting result we found was that Mexico City experienced about the same peak accelerations as the area directly above the fault that moved, due to the type of soil in Mexico City. An important lesson from this also is the value of international collaboration.

I know that supporting more strong motion instruments at major faults around the world is expensive. The advantage is that we stand to learn the answers to some of our fundamental questions sooner than we would if we wait for the same type of earthquake in California. That could reduce uncertainties for design of structures here; over time, the greater economic benefit would far outweigh the cost of the international experiment.

SCEC: Back to the question of support. What other avenues of support exist for groups such as yours (i.e., private industry) and what trade-offs may exist when you conduct research with industry support?

Glossary of Engineering Seismology Terms

Source physics: how one side of the fault slips past the other, and the physical principles that drive the slip

Wave propagation: how the seismic waves get from the fault to wherever they are going.

Scattering: an important part of wave propagation. Scattering means some of the energy goes off in different directions rather than traveling in a straight line. Think of baseball: a strong centerfielder trying to throw a ball to home plate might be able to throw it in a straight line all the way, but he might also throw it to shortstop, who throws it to third base, who throws it to home. It's an indirect route, but the ball still gets there. Likewise, if there are obstacles at different locations in the Earth, the seismic waves might take an indirect route. Complexity causes "packets" of energy to arrive at different times.

Empirical Green's functions: recordings of waves from very small earthquakes, which are more abundant than large ones, that can be used to predict strong ground motions. This is done by "scaling up" the small seismograms.

JA: There's occasionally the opportunity to get involved in a design project through an engineering consulting firm, but I don't make any effort to pursue those projects, so I don't do that very much. A significant source of support for our group has been from Pacific Gas and Electric through PEER (Pacific Earthquake Engineering Research Center). That is more like private industry than like SCEC. We've also had support from the grants programs of the National Science Foundation, the US Geological Survey, and the California Strong Motion Instrumentation Program. The trade-offs question is easy. Support from private industry is very much more focused—driven by strict deadlines. You may not have much time to think through and try to solve all the difficulties in detail. You have to come up with your best answer given the time constraints that are available. But the interaction is very valuable. On those projects, you find out what exactly are the problems that need to be solved. It's quite common to realize that their problems are actually pointing towards fundamental research questions.

SCEC: For instance?

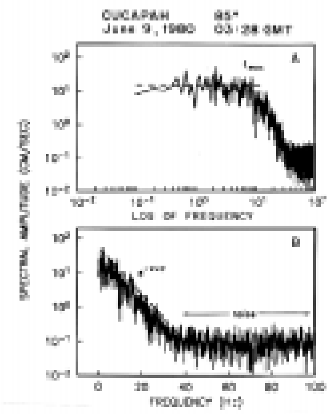
JA: For instance, right now we're dealing with "kappa" at Yucca Mountain. That's a parameter that Sue Hough (USGS Pasadena) and I defined several years ago to describe the spectral shape of high frequency accelerograms. There are some fundamental questions about its physics that we're being forced to deal with as a result of the way we are using it for the Yucca Mountain project. We don't understand why there is so much variability from one earthquake to the next.

SCEC: Can you explain this further? Why is this important to the Yucca Mountain project?

JA: Yucca Mountain has been using synthetic seismograms, among other techniques, to characterize what the ground motions might be in the (unlikely) event of an earthquake there. It's not very seismically active and there's not much data to work with, so synthetic seismograms play a more significant role. One constraint on the synthetic seismograms is that they should have the same value of kappa as observations from small earthquakes. So it's not a comfortable situation when kappa is more variable among small earthquakes than you think it ought to be.

SCEC: A recent paper you authored that was published in Seismological Research Letters (January-February 1999) addresses uncertainties associated with using a catalog of recorded earthquakes as a proxy when calculating expected ground motions for one particular site and one particular fault. Can you explain how the "ergodic assumption," as this is called, is used in hazard calculations, and whether the issue of uncertainties associated with it have an important impact on results?

JA: This is a challenge to explain, since some readers may be baffled by terminology like "ergodic," "aleatory uncertainty," and "epistemic uncertainty." But our results potentially contribute to solve a significant puzzle. The puzzle is that there are old, precariously balanced rocks within sight of the San Andreas fault. The *SCEC Quarterly Newsletter*, Vol. 4, No. 1, featured one on the cover.



Fourier amplitude spectrum of the N85°E component of strong motion acceleration recorded at Cucapah during the Mexicali Valley earthquake of June 9, 1980 (M 6.2). Accelerograph was a digital recorder that samples at a rate of 200/sec. (A) Log-log axes. (B) Linear-log axes, illustrating the definition of the parameter kappa (k). This figure is from the paper by Anderson and Hough (1984) that first defined kappa.

The San Andreas fault is in the background, 15 km away. PSHA (Probabilistic Seismic Hazard Analysis), as that previous article pointed out, predicts that ground accelerations sufficient to topple those rocks should have occurred many times in the lifetime of those rocks. That forced us to think more carefully about the PSHA process. We suggested that the problem arises with how we enter the ground motions and their uncertainties into a PSHA. On average, our observations of ground motions vary about prediction equations within a range of about plus or minus a multiplicative factor of two. This is a standard deviation of a probability distribution, so with enough cases there are observations that vary by even more. That is predominantly a spatial variability of ground motions—typically our data are dominated by a few large earthquakes that have given a lot of observations at a lot of different places. The basic PSHA takes that uncertainty in the predictions and treats it as if it is the variability over time. That is what we call the "ergodic assumption." In this model, if we could record ground motions at the same site from a dozen characteristic earthquakes on the San Andreas fault north of Los Angeles, there would be a dozen different ground motions, and they would vary over a range from one half of the mean prediction to twice of the mean prediction, and even more. With this model, if you wait long enough at any one place next to the San Andreas fault, you get really extreme accelerations. This is probably why the PSHA predicts accelerations that would topple precarious rocks. A solution had already been formulated before we wrote that paper. The uncertainty should be divided into two parts. Epistemic uncertainty covers what we don't know about the path and site effects. Aleatory uncertainty covers randomness that comes in from the differences in the source from one San Andreas earthquake to the next. We demonstrated that if most of the uncertainty is epistemic, then the contradiction would go away. A big challenge that remains is to figure out how much of the total uncertainty falls into each category. If the great earthquakes on the San Andreas ruptured in an identical way every time, all the uncertainty would be epistemic. The ground motion at the site would be identical in every earthquake. If it doesn't knock down a precarious rock the first time, then it never will unless geological processes keep making the rock more precarious. At some of the precarious rock sites, Jim Brune makes a convincing case that the geological processes are very slow now.

SCEC: From your perspective as director of the Nevada Seismological Laboratory, what is the impact of SCEC?

JA: SCEC has given the seismological community a transportable model for attacking the scientific and social issues associated with earthquakes. We need to continue a center in California to study earthquake physics. However, the rest of the country also needs research of the type that SCEC carried out in southern California. We should have a similar center for the Great Basin, one for the eastern U.S, and one for the parts of the country threatened by subduction zone earthquakes. These four centers would each be focused on a different tectonic style. This would be an extremely effective way to promote a greater interaction of earth scientists, scientific discovery, and outreach—everything that SCEC does—in the rest of the country. ■

Tales from the Front

By Susan Hough

Best-Laid Plans

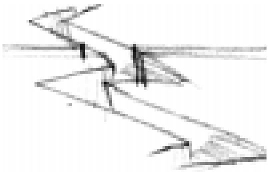
I don't remember what my long-term plans were when I took my dog for a walk on one rainy October night in New York back in 1989, but I do remember my short-term plan. I was going to get home, dry off, and watch a World Series game on television. The baseball game didn't happen, of course; I spent a long night at Lamont instead. A mere 24 hours after that, I was eating a late dinner at a Thai restaurant in Berkeley, feeling like I must've somehow wandered into a Star Trek movie and been whisked away by the transporter beam.

A recent SCEC-sponsored workshop on earthquake response seemed like an appropriate occasion to pester a few of my colleagues for their stories. How had an earthquake changed their plans and lives in recent years? Oddly, the first three people I asked all had stories about the same earthquake.

CDMG geologist Jerry Treiman first identified the M 7.2 1992 Landers earthquake as having thrown a monkey wrench into his plans for a family camping trip to, of all places, Big Bear. His family did eventually make the trip, and Jerry was able to break away from his fieldwork at times to join them. Did they feel a lot of aftershocks? On the crystalline terrain of the San Bernardino Mountains, reportedly not (providing evidence that there really is something to this business of site response).

USC geologist Jim Dolan identified Landers as having been a singularly ill-timed event in his life. He had carefully planned to take that Sunday off, his first day away from work in nearly two months. He'd even bought the early edition of the Sunday *New York Times*, in preparation for his day of leisure. At 10 o'clock the next morning, instead of sitting at his kitchen table with the paper and a cup of coffee, Jim was in the Mojave Desert making his first reconnaisance of the surface rupture. Did he ever get back to the newspaper? Nope.

The Landers earthquake was also memorable for USC seismologist Ned Field, who, in 1992, was at Lamont. Ned reports having driven into the lab early that day with fellow graduate student Vegan Aharonian. On their way in, Ned joked that, with their luck, a major earthquake would happen, and they'd be the only two people around to deal with it. Not too many minutes later, Vegan found Ned in the computer room and let him know that they'd gotten their earthquake. Two days after that, Ned was in the Coachella Valley with fellow Lamont researchers Paul Friberg and Noel Barstow. They spent a week in the field, chasing basin edge effects and hoping their unreinforced masonry hotel wouldn't collapse if the earth had yet another major temblor up its sleeve.



Another Lamont scientist, Nano Seeber (who was not at the earthquake response workshop) recalled the Landers earthquake in a different light. Although his prior plans were also scrubbed for a Monday morning trip to southern California, he recalled his impromptu fieldwork adventure as having been more enjoyable and productive than the daily, computer-oriented grind he left behind.

The SCEC workshop was a success. Attendees left with a sense of optimism regarding our ability to lay the groundwork to optimize our chances of a successful earthquake response the next time one is called for. One is left wondering, though—is "next time" 10 years, or 10 minutes away? 24 hours from now, are you going to be at the appointment on your calendar, or some place else? It's like the Microsoft slogan with a twist—not "Where do you want to go today," but "Where are you going to be tomorrow?"

And if, underneath it all, we didn't love it at least a little, we wouldn't be in the earthquake-chasing business in the first place. ■

Interested in sharing a field-work story of your own?
hough@gps.caltech.edu
WWW-SOCAL.WR.USGS.GOV/HOUGH/

Holocene Activity of the Rose Canyon Fault Zone

By Scott C. Lindvall and Thomas K. Rockwell

The northwest striking Rose Canyon fault zone, which bisects the city of San Diego, comprises a complex set of anastomosing and en echelon fault strands that include the Rose Canyon, Mount Soledad, Country Club, Mission Bay, Old Town, Spanish Bight, Coronado, and Silver Strand faults, in addition to many other secondary faults (Figure 1) (Kennedy, 1975; Kennedy and Welday, 1980). Offshore mapping of faults in the Southern California Borderland using seismic stratigraphic techniques (Legg, 1985; Legg and Kennedy, 1991; Fischer and Mills, 1991) has shown that the Rose Canyon fault zone extends northwest and joins the Newport-Inglewood fault zone (Figure 2). The continuity of faulting along this zone led Fischer and Mills (1991) to conclude that the Newport-Inglewood and Rose Canyon faults represent a single structural element.

> *The dip-slip motion along this fault has provided San Diego with much of its aesthetic beauty.*

Although motion on the Rose Canyon fault zone is generally considered to be right-lateral strike-slip (Kennedy, 1975), individual strands within the fault zone display various combinations of dip slip and strike slip. The variable sense of dip-slip motion along this fault has locally resulted in the uplift of Mount Soledad, the depression of San Diego Bay, and other physiographic features that provide San Diego with much of its aesthetic beauty.

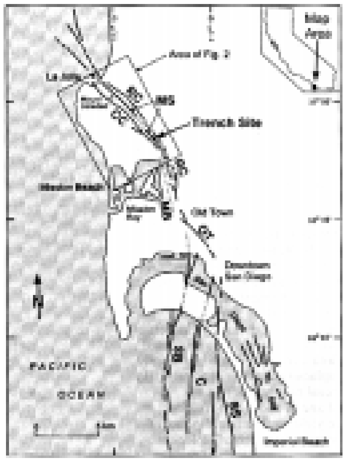
In 1989, two-dimensional trenching of the fault on the lowest terrace of Rose Creek demonstrated that the fault displaces Holocene deposits and showed that considerable strike slip was required to explain stratigraphic mismatches across individual strands of the fault (Lindvall et al., 1990; Rockwell and Lindvall, 1990). Subsequent three-dimensional trenching at the Rose Creek site was able to determine a slip rate and recognize at least three paleo-earthquakes (Lindvall and Rockwell, 1995). More recent studies have better constrained the timing of the most recent surface-rupturing earthquake (Rockwell and Murbach, 1998).

This article presents information from a three-dimensional paleoseismic trenching study and other investigations and summarizes our current understanding of the Holocene behavior of the Rose Canyon fault zone.

Rose Creek Study Site

Based on our tectonic geomorphic analysis, we selected a site where the southeastern continuation of the Mount Soledad fault crosses the lowest terrace of Rose Creek and formed a low, east-facing scarp. The Rose Creek site, which was graded in 1960 and is now occupied by an asphalt-covered parking lot of the San Diego Gas & Electric Beach Cities Operating Center, is one of the few accessible locations in this urban environment where young, surficial sediments were deposited across the fault.

> *The most recent large surface rupture on the Rose Canyon fault occurred during the past few hundred years.*



All figures: Lindvall and Rockwell

Figure 1. Generalized map showing major strands of the Rose Canyon fault zone and major geographic features of the San Diego area. Individual faults within the zone are the Country Club (CC), Mount Soledad (MS), Rose Canyon (RC), Mission Bay (MB), Old Town (OT), Spanish Bight (SB), Coronado (C), and Silver Strand (SS). Faults are dashed where approximately located, dotted where concealed.

In 1989 we excavated a single trench across the fault to determine the style and width of faulting and the type of sediment at the Rose Creek site (Figure 3). The 22-m-long trench exposed a 1.5 to 2.0-m-thick section of artificial fill immediately below the paved parking lot surface. Underlying the fill we exposed a section of faulted clayey to silty sand on which the surficial soils were partially intact. The fill was emplaced in 1960 without disturbing the scarp or the organic-rich A horizon northeast of the fault (Figures 3 and 4). However, southwest of the fault, grading removed much of the A and B_t soil horizons. Consequently, the original ground surface, including the fault scarp, was effectively buried and preserved or slightly modified from that seen in the 1941 air photos. The fault was expressed in the trench expo-

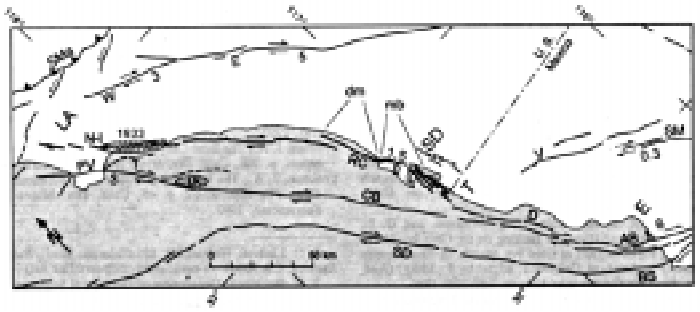


Figure 2. Regional map showing major northwest-striking dextral-slip fault zones including the Newport-Inglewood (N-I)–Rose Canyon (RC) fault zone that extends from San Diego to Los Angeles. Other faults are Sierra Madre (SMa), Whittier, (W), Elsinore (E), Palos Verdes (PV), THUMS-Huntington Beach (T), Coronado Bank (CB), Descanso (D), Vallecitos (V), San Miguel (SM), Agua Blanca (AB), and Bahia Soledad (BS) faults. Labeled cities are Los Angeles (LA), San Diego (SD), and Ensenada (E). The source zone of the 1933 Long Beach earthquake is denoted by the hatched pattern, and the dark shaded area offshore is Lausson Knoll (LK). Numbers refer to fault slip rates in millimeters per year.

sure as a flower-type structure with several strands splaying outward toward the surface. The individual fault strands offset Holocene strata across a zone about 2 m wide. Some strands crosscut others and exhibit a complex micromorphology, suggestive of multiple slip events. Nearly all fault strands in the trench wall exhibit an apparent west-side-up component of slip, which is consistent with the east-facing scarp seen in the 1941 photographs. The most recently active fault strands completely offset the A, E, and B_t soil horizons that marked the natural ground surface prior to grading and development in 1960 (Figure 3).

Radiocarbon dating of detrital charcoal samples revealed that the stratigraphic section exposed in the trench was early to middle Holocene in age. This initial phase of trenching at the Rose Creek site demonstrated that the Rose Canyon fault zone was Holocene active. In addition, the sharp, distinct contacts of the faults and surficial soil horizons suggest that the most recent earthquake likely occurred only a few hundred years ago.

The evidence suggests the last large surface rupture may have involved the entire onshore portion of the fault zone.

Three-Dimensional Trenching

Two-dimensional fault exposures on a trench wall oriented perpendicular to the fault cannot resolve horizontal slip. Previous studies of strike-slip faults (Sharp, 1981; Sieh, 1984; Rockwell et al., 1986) have demonstrated the effectiveness of three-dimensional trenching in resolving both horizontal and vertical deformation, and we employed these methods at the Rose Creek site. Based on the results of our first trench (T-1), we reoccupied this site with the intent of exposing the fault zone in three dimensions and resolving the slip by mapping displaced fluvial features.

Initially, we excavated two fault-parallel trenches that straddle the fault (Figure 6) immediately northwest of trench T-1. These trenches were used to establish the site's stratigraphy and to identify fluvial features or sedimentary structures that could be used as piercing points for quantifying the amount of horizontal offset.

In the 20-m-long trench T-2 (Figure 4), we found only one such feature, a gravel-filled channel oriented normal to the fault. The channel's cross section was exposed in both the northeast and southwest walls of the trench and was the only gravelly channel deposit in trenches T-1, T-2, or T-3. The coarse-grained channel fill was distinctive amidst the relatively fine-grained, weakly stratified, silty to clayey sand deposits that characterize most of the exposures. The gravel channel was not present in trench T-3 west of the fault zone, because the section containing the gravel had been eroded or stripped when the northwest corner of the site was graded in 1960. Therefore we had to expose the channel in hand-dug excavations across the fault zone beginning with trench T-2.

After logging trenches T-2 and T-3, we excavated the artificial fill at the site down to the top of the natural deposits in order to trace the gravel channel to and across the several strands of the fault. This resulted in a ~12 x 18 m rectangular excavation that was 2-2.5 m deep with 1:1 slopes along the sides (Figure 7). From the floor of the pit, we first excavated a short trench (T-4) across the fault to re-expose the fault zone (Figure 6). We also re-excavated part of trench T-2 (trench T-2A) to re-expose the channel. A series of connecting trenches were then excavated by hand to expose the channel to and across different strands of the fault (trenches T-5 to T-11), leaving the channel preserved in intact blocks of sediment (Figures 6 and 7).

Stratigraphy

The faulted sediments underlying the artificial fill consist predominantly of a sequence of clayey to silty sand deposits that are locally weakly to moderately stratified (unit C). Also within unit C are several

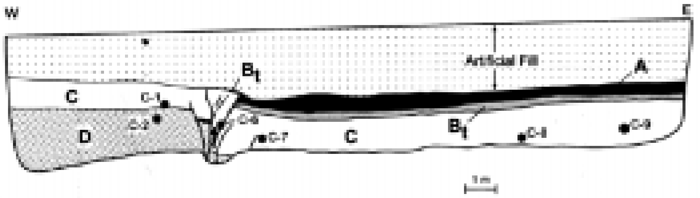


Figure 3. Generalized log of trench T-1. Note the upward flowering structure, mismatch of some stratigraphic units, and location of ^{14}C samples (solid circles). Mapped units are: A, modern A soil horizon; B_t, B_t (argillic) soil horizon; C, stratified overbank alluvium; D, gravelly colluvium. Much of the A and B_t horizons have been stripped from the southwest side of the fault.

small lenses and sheets of fine, moderately to well-sorted sand and millimeter- to centimeter-thick layers of clay that generally extend laterally for as much as several meters. These stratified sediments overlie massively bedded, gravelly silty clay deposits (unit D) that were exposed at the base of most of our trenches west of the fault.

The most recent event on the Rose Canyon fault zone was likely on the order of M 7.

Except where deformed within the fault zone, the stratigraphy is virtually horizontal throughout our trench exposures (Figures 3 and 4).

The sediments comprising unit C (Figures 3 and 4) are interpreted to be fluvial overbank sediments from Rose Creek because they are fine grained and thinly bedded, maintain fairly uniform thickness, and are laterally continuous over several meters. Three weak buried soil A horizons within unit C allow for its division into four subunits, C_1 through C_4 (Figure 4). Not all buried A horizons were recognized in every exposure, but the lower two are commonly preserved and were the most useful for correlating between exposures and across faults. These buried soils, which represent short hiatuses in deposition, are bioturbated, have a darker color than the surrounding sediments, and obliterate stratification within the overbank deposits. The best preserved and most laterally continuous stringers of sand and clay are generally those that directly overlie the buried A horizons and have had the least post-depositional disturbance.

Unit D is a gravelly silty clay capped by a buried A horizon. This distinct unit is considerably darker, more massive, and contains more clay than unit C. Furthermore, clasts ranging from pebbles to large cobbles are common throughout this unit. In trench T-8, several cobbles were grouped together near the top of unit D_1 and were associated with cultural artifacts. Based on the sorting, color, and massive character of unit D, we interpret this to be primarily a colluvial or debris-flow deposit.

The modern soil, with a dark, organic-rich A (topsoil) horizon, a discontinuous E (albic) horizon, and a weakly to moderately developed B_t (argillic) horizon, is developed in the upper 60-80 cm of the section below the artificial fill. The argillic horizon indicates that this soil was exposed at the surface substantially longer than at any of the buried A horizons.

Gravel-Filled Channel

Trench T-2 exposed a single gravel-filled channel trending nearly perpendicular to the fault that we used as the piercing line. The channel is stratigraphically part of unit C_2 in all exposures east of the fault (Figure 4). Within the fault zone, the channel fills the base of a narrow rill or gully that incised through unit C_2 and into unit C_3. West of the westernmost fault strand, the channel was removed prior to or during grading of the site in 1960.

The channel contains coarse sandy gravel to gravelly sand in the thalweg. These coarse deposits fine upward into, and in some places become indistinguishable with, the overlying fine-grained overbank deposits. The sandy gravel at the base of the channel is 30-50 cm wide and 10-25 cm deep. The subangular to rounded clasts were generally smaller than 5 cm in this linear deposit that flowed east to west across the Rose Creek terrace.

Five samples of detrital charcoal from units C_2, C_3, C_4, and D_1 were dated by accelerator mass spectrometry techniques and yielded dendrochronologically calibrated ages ranging from 8.1 to 9.4 kyr. The maximum age of unit C_2 is best constrained by the youngest date from the underlying unit C_3, or about 8.1 kyr. Because the channel is incised into unit C_2 this date also represents the maximum age of the channel. The actual age of unit C_2 and the channel, however, is probably not significantly younger than 8.1 kyr.

Dating of shells from fissures filled by an overlying faulted Indian midden deposit constrains the timing of the latest rupture to after A.D.1523.

Determination of Slip and Slip Rate

The amount of slip was determined by excavating the distinctive gravel-filled channel into and across the several strands of the fault zone. The position of the channel, individual fault strands, and each trench wall was accurately mapped using a surveying instrument (Figure 6). Based on this map, we reconstructed the channel such that adjacent channel pieces were realigned (Figure 8). We backslipped the westernmost strand to the location where the stratigraphic unit containing the channel was cut out during the grading of 1960; because the channel may have been present even farther to the northwest, the amount of slip in the recon-

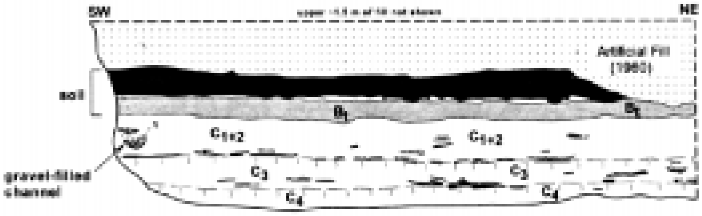


Figure 4. Log of southeastern part of southwest wall of fault-parallel trench T-2 showing flat-lying stratigraphy of the site and buried channel that was used as a piercing line. Units A, E, and B_t represent the topsoil, albic, and argillic soil horizons that formed in silty to clayey sands of unit C. Unit C was subdivided into four subunits (C_1-C_4). In this exposure, units C_1 and C_2 are undifferentiated. The subunits are separated by weak buried A horizons (short vertical wavy lines). Minor discontinuous lenses of sand (stipple) and clay (solid) are present throughout unit C.

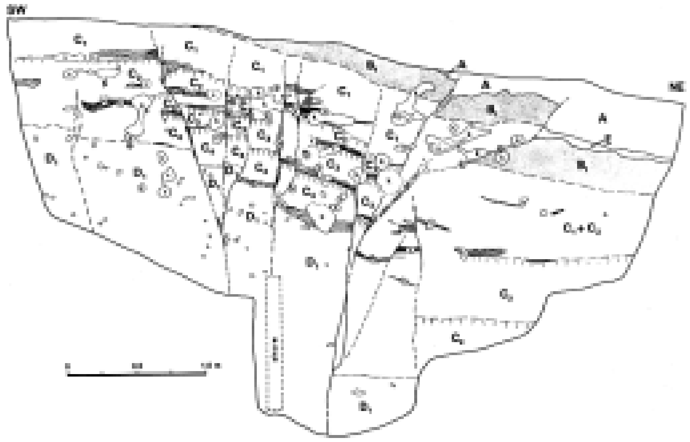


Figure 5. Detailed map of the northwest wall of trench T-4 showing the primary structural elements and stratigraphic units. Unit C was subdivided on the basis of weakly developed buried A horizons (shown as short vertical wavy lines). Unit C contains thin beds and stringers of clay (solid), silt (open), and sand (stippled). Evidence of bioturbation is shown by the numerous krotovina (k). Note that the northeastern strands displace the A, E, and B_t soil horizons, which is the result of the most recent surface rupture, whereas the southwestern strands could not be traced to the top of unit C_1.

struction is a minimum value. This reconstruction results in a minimum of 8.7 m of right-lateral strike-slip that postdates deposition of the gravel channel. Vertical displacement of the channel across all but the westernmost strand was consistently west-side-up and totaled 0.7 m. Although no piercing points were available to measure the vertical slip across the westernmost strand, the 11-cm vertical separation of the top of Unit D in trench T-9 implies that this fault produced only minor vertical slip. We estimate a horizontal to vertical slip ratio of about 10:1 for the Mount Soledad fault (zone) at the Rose Creek site.

> *We suggest the overall slip rate is between 1.1 and 2 mm/yr.*

To establish a conservative minimum slip rate, we use the minimum of 8.7 m of brittle slip, assuming no rotational deformation, and a maximum age of the channel of 8.1 kya. This yields a minimum early Holocene to present slip rate of 1.1 mm/yr. This rate is a minimum from the perspective that (1) the slip determination is a minimum value, (2) the age of the piercing channel is a maximum, and (3) other strands of the Rose Canyon fault zone may also be active. If the channel is as much as 2 kyr younger than the underlying dated strata, then the slip rate is about 1.5 mm/yr. If the change in channel trend through the fault zone is the result of horizontal drag, the lateral displacement is at least 10 m, which increases the slip rate to nearly 1.7 mm/yr.

Based on the above uncertainties and allowing for the probability of some slip on other strands of the fault zone, we suggest that the overall slip rate is between 1.1 and 2 mm/yr, with a best estimate of about 1.5 mm/yr. The lower bound of 1.1 mm/yr is determined by our trenching results, whereas the upper bound of 2 mm/yr is estimated from a comparison of the geomorphology associated with the three principal strands of the Rose Canyon fault zone. Based on this comparison, it appears likely that the Mount Soledad strand carries the majority of the slip.

Timing of Past Events

From the trench exposures, we have evidence for at least three events since about 8.1 kyr. The earliest event is suggested by a low scarp into which the gravel-filled channel incised. East of the fault, the channel is within unit C_2 (Figure 4). As the channel crosses the fault zone to the west, it incises into progressively older and deeper strata so that the channel cuts into units C_3 and the top of C_4. This indicates the presence of a scarp that formed between deposition of unit C_3 and the formation of the channel. Furthermore, units C_1 and C_2 thin to the west across this scarp (Figure 5) indicating that scarp formation occurred soon after the deposition of unit C_3. Therefore the event that produced the scarp must have occurred soon after about 8.1 kyr, the maximum age of unit C_3. The minimum of 8.7 m of slip on the channel occurred after this ~8.1 kyr event.

A second event is indicated by a group of fault splays that displace unit C_1 but do not displace the base of the B_t soil horizon (Figure 5). The time of this event is unconstrained, but there must have been sufficient time for soil development to obliterate the fault traces in the soil.

The most recent event ruptured the ground surface and abruptly displaced all soil horizons on the eastern strands of the fault zone in trenches T-1 and T-4 (Figures 3 and 5). The absence of significant bioturbation where the B_t horizon is juxtaposed over the A horizon indicates that this event is very

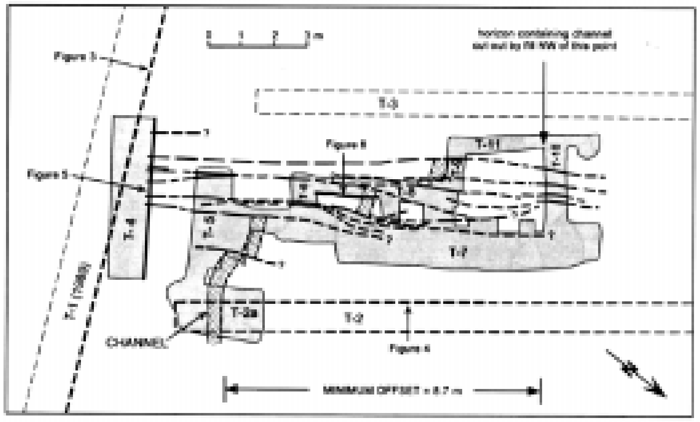


Figure 6. Plan view map of trenches excavated to determine displacement of the buried channel across strands of the fault. Channel is shown by stipple pattern. Faults are heavy lines, dashed where approximately located, queried where uncertain, and are shown at the stratigraphic level of the channel. Trenches shown with a dashed line were excavated from the parking lot surface, all others excavated by hand from the pit floor. Portions of trench margins shown in bold indicate location of other figures.

Figure 7. Southward view of hand-excavated trenches dug into base of the large rectangular excavation, which approximately coincides with the base of artificial fill. Faults strike from upper left to lower right corner of photograph. Note cars in upper left corner for scale.

young, probably less than several hundred years. This interpretation is supported by other studies, which document the latest earthquake as occurring on the order of ~300 years ago, as discussed further below.

A minimum of three events in the last 8.1 kyr implies a maximum recurrence interval on the order of 4,000 years. This also requires that the last two events produced an average of more than 4 m of slip per event. The average recurrence interval could be substantially less than the maximum interval of 4,000 years. These data indicate that the recurrence interval for large surface-rupturing earthquakes is on the order of a few thousand years.

Most Recent Event

Multiple studies indicate that the most recent large surface rupture on the Rose Canyon fault occurred during the past few hundred years. Near Mission Bay at the Rose Creek site, the abrupt, distinct faulted contacts within the surficial soil horizons (Figures 3 and 5) imply that very little time has elapsed since the latest event. The absence of significant bioturbation where the B_t horizon is juxtaposed over the A horizon indicates that this event is very young, probably occurring less than 500 years ago (Lindvall and Rockwell, 1995).

This estimate agrees with the results of trenching studies in the downtown San Diego area that indicate a surface-rupturing event occurred on strands of the Rose Canyon fault zone post-A.D.1420 The timing of this event is based on radiocarbon ages of detrital charcoal in fissure fillings from the Sports Arena site (Woodward-Clyde Consultants, 1994). The lack of historical accounts of large earthquakes in the San Diego area constrains the timing of this event between A.D. 1420 and 1769, the year the Spanish established the first mission in San Diego.

Rockwell and Murbach (1998) demonstrated that the most recent rupture in the La Jolla area is consistent with the timing of the latest earthquake on portions of the fault zone that traverse the Mission Bay and downtown areas. Dating of shells from fissures filled by an overlying faulted Indian midden deposit constrains the timing of the latest rupture to post-A.D.1523 Using the calibrated lower bound of A.D. 1523 and an upper one of A.D.1769 yields a best estimate of A.D. 1650 ± 125 for the age of this event (Rockwell and Murbach, 1998). Because this date is indistinguishable from the dates obtained from the downtown study (Woodward-Clyde Consultants, 1994), it is plausible, if not likely, that they represent the same earthquake. It is possible, however, that these data could represent different earthquake ruptures that are closely separated in time and space, rather than a single event.

The evidence for a near-historical event at all three sites suggests that the last large surface rupture may have involved the entire onshore portion of the fault zone. Slip in this most recent event has been estimated at both the Rose Creek site and in La Jolla near the coast. Based on re-evaluation of the three-dimensional data from Lindvall and Rockwell (1995), it appears that the most recent event produced ~3 m of slip on the eastern fault strands at the Rose Creek site (Rockwell and Murbach, 1998). This is consistent with a mini-

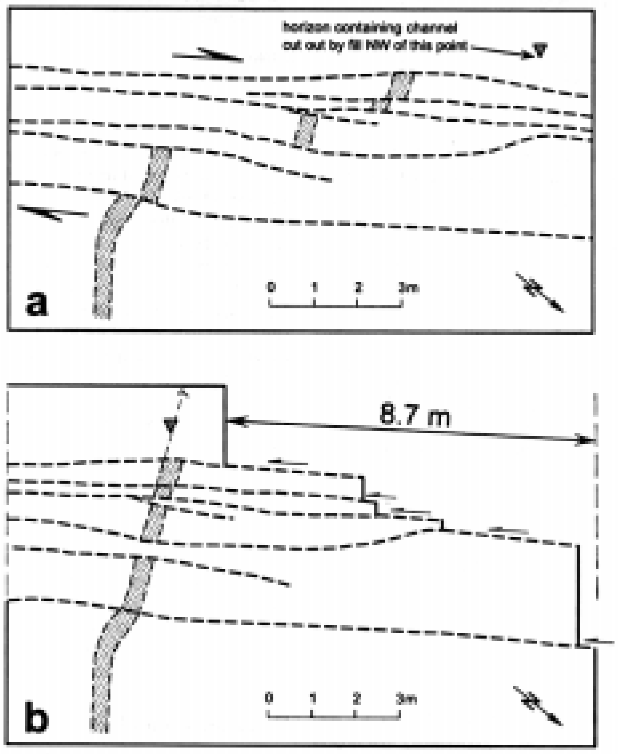


Figure 8. Generalized map and reconstruction of the faulted channel. The reconstruction provides a minimum value of lateral offset because the stratigraphic units containing the channel are missing west of the westernmost fault strand northwest of the shaded triangle.

mum displacement of >1 m estimated at the La Jolla site (Rockwell and Murbach, 1998), which is located over 5 km to the north. Based on the amount of slip and a minimum rupture length of at least the onshore portion of the fault zone, the most recent event that occurred on Rose Canyon fault zone was likely on the order of ~M 7.

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Museum Features Work of SCEC Scientist

SCEC’s Thomas Rockwell (San Diego State University) was interviewed about his research on the paleoseismicity of the San Andreas fault by the American Museum of Natural History for the Hall of Planet Earth, a new permanent exhibition devoted to earth sciences. A portion of that filmed interview will be shown in the new hall.

NISEE Releases Software on CD-ROM

"NISEE Software Library CD-ROM," a comprehensive collection of 112 engineering research software programs, is available from the National Information Service for Earthquake Engineering (NISEE), University of California, Berkeley. Applications range from strong motion data processing programs to geotechnical and structural analysis tools; user documentation for all programs on the CD-ROM is available through NISEE. Cost is $139, including shipping in the U.S. Order from NISEE, University of California, Berkeley, PEER Building 451 RFS, 1301 South 46th Street, Richmond, CA 94804-4698; (510) 231-9403; fax: (510) 231-9461; INFO@NISEE.CE.BERKELEY.EDU. Web site: WWW.EERC.BERKELEY.EDU.

Strong Motion Consortium Successfully Launched

The Consortium of Organizations for Strong-Motion Observation Systems has submitted its bylaws as a public-interest nonprofit corporation for earthquake safety to the Secretary of State in Sacramento and now has an office and staff in the PEER Building in Richmond, California (COSMOS, c/o PEER, 1301 S. 46th Street, Richmond, CA 94804-4698; Tel: (510) 231-9436; fax: (510) 231-9471; email: COSMOS@PEER.BERKELEY.EDU). The launch of this umbrella consortium has met with widespread interest among earthquake engineers, emergency planners, and seismologists. COSMOS is now in a position to influence management of the new National Seismic System recently approved by Congress. A subcommittee of COSMOS has already produced recommended standards for a national repository of strong motion records.

A regular board and working committees will be elected at a general meeting of all interested persons and eligible members on September 16 following the SMIP 99 annual meeting near either Oakland or San Francisco airport. At that meeting membership fees and COSMOS operating policies will be discussed. A descriptive brochure is available on request from the above address.

Geologist Placement Service

Onsite Environmental Staffing, a placement firm for professionals in the environmental and engineering fields, has positions available ranging from entry level to registered geologists with leading mainstream geology firms in southern California. Email or fax resumes, or call to set up an interview. Erik Applebee: (714) 245-4725; (800) 338-4199; fax (714) 954-0726; EAPPLEBE@ONSITE-INC.COM

State Guide Tells How to Evaluate Liquefaction Dangers

By Mark Benthien

A new document to help engineers, geologists, and building officials evaluate and take protective measures against liquefaction hazards in southern California is now available.

Recommended Procedures for Implementation of DMG Special Publication 117—Guidelines for Analyzing and Mitigating Liquefaction Hazards in California was produced by a committee of engineers and geologists with academic, practicing, and regulatory backgrounds. The book was published by the Southern California Earthquake Center.

Liquefaction happens when loose sandy soils below the ground water lose strength because of strong ground shaking. This liquefaction could result in settling and sliding, leading to damage to buildings on such soils. The new report asserts that liquefaction is sufficiently understood now so that soil behavior during earthquakes can be predicted. Therefore, the consequences of that behavior can be planned for and damage possibly avoided.

Thomas Henyey, director of SCEC, responds to a question.

Charles Real describes the Seismic Hazard Mapping Act to assembled reporters, as Thomas Blake looks on.

The report contains recommendations for what constitutes an adequate evaluation of the liquefaction potential of an area, along with the hazards that arise from liquefaction, including settling, lateral spreading, flow slides, and loss of bearing capacity. The report presents an overview of the recommended methods of analysis and addresses the common technologies available to mitigate the effects of liquefaction. Also discussed are the merits of soil improvement, structural design for the effects of liquefaction, and the inherent risks associated with such decisions.

The report is a summary of 18 months of study and deliberation in response to the California Department of Conservation's Division of Mines and Geology (CDMG) Special Publication 117, which presents general guidelines for evaluating and mitigating seismically induced soil liquefaction and landslides.

SP 117 is an outcome of the California Seismic Hazards Mapping Act (SHMA), which requires that seismic hazards, including liquefaction, be evaluated and mitigated, if needed, for all new construction in the state. The state is now publishing maps delineating areas that are believed to be susceptible to both liquefaction and landslide hazard.

With the release of SP 117, building officials in the Department of Building and Safety of the City of Los Angeles and the Department of Public Works of the County of Los Angeles requested assistance with developing standard procedures to implement the new requirements for projects requiring their review. They sought cooperation from other agencies in southern California. Officials from the counties of Riverside, San Bernardino, San Diego, Orange, and Ventura agreed to participate; CDMG and FEMA also lent support to this effort.

Authors of the report take the stage for the afternoon discussion session. (l to r) Ted Smith, Arul Arulmoli, Abe Simantob, Geoff Martin, Marshall Lew, Charles Real, Thomas Blake, Juan Baez, and Les Youd.

Workshop Will Be Available on CD

A workshop on use of the report was conducted by its authors for city and county officials and consulting engineers on June 17, 1999, at the Davidson Conference Center at USC. The full-day workshop included a chapter-by-chapter overview of the material and afternoon panel sessions for discussion and feedback. The chapter-by-chapter overview was given using a nine-part Microsoft PowerPoint presentation and was audiotaped. The presentation will be placed onto CD-ROM along with the audio for a narrative run-through of the overview. The afternoon panel discussion sessions were videotaped. Highlights will be placed on the CD-ROM. Questions and their answers will be included. The final product will be available for sale from SCEC. Watch for an announcement of the CD-ROM's release at www.scec.org or in this newsletter.

Liquefaction Implementation Committee

Geoffrey R. Martin (co-chair), Department of Civil Engineering, USC

Marshall Lew (co-chair), Law/Crandall, a Division of Law Engineering and Environmental Services, Los Angeles

K. Arulmoli, Earth Mechanics, Inc., Fountain Valley

Juan I. Baez, Hayward Baker, Santa Paula

Thomas F. Blake, Fugro West, Inc., Ventura

Ebrahim Simantob, R. T. Frankian & Associates, Burbank

T. Leslie Youd, Department of Civil and Environmental Engineering, Brigham Young University

Local and state government liaisons to the committee:

Johnnie Earnest, Orange County

Fred Gharib, Los Angeles County

J. Goldhammer, San Diego County

David Hsu, City of Los Angeles

Steve Kupferman, Riverside County

Jim O'Tousa, Ventura County

Charles R. Real, DCMG

Wes Reeder, San Bernardino County

The agencies' request for assistance was made through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE) in 1997. A group of practicing geotechnical engineers and engineering geologists was assembled to develop implementation procedures. The liquefaction implementation committee was organized through the auspices of SCEC and convened at SCEC's administrative headquarters at USC. Its task was to aid the several counties and many cities in southern California with implementing SHMA for liquefaction hazards and to provide an overview of analysis techniques and methods of mitigation.

The committee's report was released on April 19, 1999, and a press briefing was held at USC to announce its availability. Members of the implementation committee were present to answer questions from the media. Three television news stations, two radio stations, and two newspapers were present.

Copies of the report can be obtained by using the order form included in this newsletter or by calling 213-740-5843.

Copies of SP117 can be obtained by sending a check for $15 payable to Division of Mines and Geology to P.O. Box 2980, Sacramento, CA 95814. On the memo line of the check, write "SP117." Do not add tax or shipping. ■

Thumbnail Sketches of This Year's Interns

Internship program coordinator Mark Benthien recently announced the participants in the sixth annual SCEC Summer Internship Program. Here is a list of the students, their research mentors, projects and goals, and personal goals.

Natanya Black
Geology, UC Santa Barbara

Tom Rockwell, CSU San Diego

Reconstruction of Trench Logs as a Test for Interpreted Paleoseismic Events

Personal goals: after obtaining my undergraduate degree, I intend to continue working toward my M.S. and Ph.D. My goal is to work at an academic institution doing research and teaching. I hope to do research as a geologist in seismic studies and petrology. Teaching is another very important aspiration for me. I want to work toward a broader understanding of geology and earth mechanics in our society. I will endeavor to discover new geologic perspectives in my future research, and I hope to be able to convey that knowledge to others.

Project goals: the goals of this project are very relevant to science and society, because earthquakes not only have the potential to cause millions of dollars in damage and terrible loss of life, but in a more insidious way, they can produce an underlying panic or fear in the society. One potential solution to this fear is through the study and explanation of the earthquake phenomenon. One element of this is to study the past occurrences of earthquakes in Southern California to better understand how often, and when, future earthquakes are likely to occur on Southern California's many earthquake faults. Ultimately, this information can serve to lessen the anxiety that people experience as they better comprehend that earthquakes are not random processes (acts of God), but rather occur in a systematic way due to loading on the Southern California faults. Developing methods to correctly interpret past earthquakes is critical in the evolving field of paleoseismology and for the correct future assessment of seismic activity of Southern California's faults. This knowledge can bring a sense of security, through better education and preparedness, to the society as a whole.

Debra Einstein
Environmental Analysis & Design, UC Irvine

Mark Legg, Legg Geophysical

Compile Updated Fault Maps of the Southern California Continental Borderland (Offshore Region) for the Master Model

Personal goals: I would like to work in the field of environmental assessment and get hands-on experience. I want to learn more about faults/fault zones so that I may use that knowledge in assessing different areas. This becomes especially important in California.

Project goals: a project of this magnitude is important, especially for SCEC. To be able to read on a map faults/fault zones and seismicity is especially significant for assessing types of hazards accompanied by building in these areas.

Marie Herrera Adsetts
Geophysics, UC Santa Barbara

Bruce P. Luyendyk, UC Santa Barbara

Mapping Small-scale Crustal Deformation using Paleomagnetic Vectors and GIS.

Personal goals: I'd like to understand the research processes involved because I understand it's a difficult and lengthy process. I'd like to become familiar with the geologic history of this particular area and its relevant significance. I would also like to be able to communicate this information successfully in both speaking and writing. Academically, I'd like to pursue a master's degree in the geological sciences but I must first obtain my bachelor's degree. My plan is to enter graduate school by the fall of 2001.

My career goal is rather unstructured at the moment. After obtaining my B.S. degree, I hope to work for the USGS as an intern to gain some experience and attend graduate school. After completing my master's degree, I'd like to obtain a position involving seismology. I am also entertaining the idea of teaching either geology or mathematics at a community college.

Project goals: mapping details of the crustal rotations indicates sizes of blocks where strain has occurred. The detailed mapping history of deformation is relevant because it suggests how southern California has deformed, as well as how it may be deforming presently. Thoroughly understanding the patterns in paleomagnetic data and faults for the western transverse ranges allows for more precise predictions involving crustal rotations and fault and basin development for the southern California region.

Grant Kier
Geology, Sociology/Philosophy, University of Colorado

Karl Mueller, University of Colorado

Determining Activity of the Oceanside detachment Offshore Southern California

Personal goals: my long-term goal is to teach earth science in either a high school or college setting. I wish to integrate my undergraduate studies in sociology, philosophy, and geology toward studies of natural hazards that have the potential to affect society. Upon completing my undergraduate work, I will apply to master's programs in geology at research-oriented universities. After completing a master's, I hope to work in an educational setting for a geotechnical company.

Project goals: this project is relevant to the scientific effort to create a master model of seismic hazards for southern California. This project may also contribute to an understanding of uplifted terraces along the California coast. Should this project provide evidence for yet unknown activity along the Oceanside detachment, this project will have enormous societal impact—influencing urban planning and development and other efforts to reduce seismic hazard risk.

Christopher Lynch
Computer Science/Geology, CSU San Diego

Steven M. Day, CSU San Diego

Inversion of Teleseismic Receiver Functions via Evolutionary Programming

Personal goals: besides my interest in the computational aspect of this project, I am intensely interested in local structure and tectonics, so I'm working to develop the skills necessary to enable me to contribute to this area of research. I will graduate from SDSU in August and hope to continue my studies through a master's degree program in computational science combining computer and geological/geophysical science.

Project goals: I think this work fits into the SCEC goal of generating the "master model," which includes as a main point the need to determine the seismic wave velocities to use in computing theoretical seismograms. This code is being used to explore methods of determining the velocity structure of the crust through inversion of teleseismic receiver functions. By developing a range of techniques and comparing their results we can better verify and constrain these results, producing a more accurate model of the Earth's crust. From this we can learn to better understand the tectonic forces that affect us and develop the strategies to exist safely with seismic hazards.

Nathan Robison
Geological Engineering, University of Nevada

John Anderson, UNR Seismology Laboratory

Comparison and Refinement of Southern California Seismic Hazard Analysis

Personal goals: along with my wife and daughter, I intend to grow as a family that promotes science, bicycle riding, and common decency. I will graduate cum laude with a B.S. in geological engineering and expect to begin graduate study towards a doctorate in mining and geological engineering within the following year. Graduate work is also expected to include seismology and mechanics research. A career for the next several years in the environmental and geologic consulting industry will give way to a university position after attainment of an advanced degree.

Project goals: justifiable revision of attenuation models has the potential to save billions of dollars in public works and public and private construction costs. Establishment of techniques for reducing the uncertainty of upper-bound acceleration models may be of long-term use to the science.

Kelly Schmoker
Geology, CSU, San Bernardino

Sally McGill, CSU, San Bernardino

Paleoseismic study of the San Andreas fault near San Bernardino

Personal goals: I would like to go on to graduate school in the field of geology, focusing on paleoseismic studies. Eventually, I would like to become a professor and still do research.

Project goals: the San Bernardino segment of the San Andreas fault represents a major hazard for the Inland Empire area. It is important to know how frequently this portion of the fault produces earthquakes. Previous estimates of the probability of an earthquake on the San Bernardino segment of the San Andreas fault were about 28 percent in the next 30 years (Working Group on California Earthquake Probabilities, 1995). This was based on assuming a recurrence interval of 146 years. Prior work at the Plunge Creek site suggests that it may have been more than 350 years since the last earthquake at that site. If this is true, then either the probability of an earthquake in the next 30 years is more than 28 percent or the average recurrence interval is longer than the 146-year estimate that was used to calculate this probability. Our work this summer will help to distinguish between these two possibilities.

Ashley Streig
Geology, Occidental College

Kerry Sieh/Doug Yule, Caltech

Paleoseismic Investigation of the San Andreas Fault at Burro Flats

Personal goals: I plan on attending graduate school upon my graduation from Occidental College in May 2000. I hope to attain both my master's degree and Ph.D. in a field of geology or earth sciences. This internship is a great opportunity for me to gain research experience in a field where I hope to continue my education. Through this research project, I hope to focus my academic goals in the field of geology.

Project goals: the seismic history in Burro Flats will help us determine how frequently earthquakes happen in this region and how intense the ground shaking may be. We will determine how the fault behaves in Burro Flats between San Bernardino and Indio. Interestingly, this is the only segment of the San Andreas fault that has not had an earthquake in the last 200 years, so examination at this segment is important to the overall understanding of the San Andreas fault system. Seismic history of this region will help us gauge future activity in this region. As the population of the Inland Empire continues to grow, this information will help inhabitants prepare for future earthquakes. The results of this study will show us how large earthquakes are and how frequently they occur along this section of the fault, allowing assessment of risk in the area.

Kathryn van Roosendaal
Geophysics, CSU, Northridge

David Okaya, USC

3-D analysis of LARSE '94 data

Personal goals: my long-term goal is to obtain at least a master's degree in volcanology and geophysics. I am especially interested in geophysical modeling of magma chambers and other plutonic structures.

Project goals: the LARSE project is of great importance to the inhabitants of the Los Angeles basin and the San Fernando Valley. The Northridge earthquake drove home the importance of locating blind thrust faults and other structures far beneath the surface. The study is also important scientifically for its look into the structure of the lithosphere and the workings of plate tectonics.

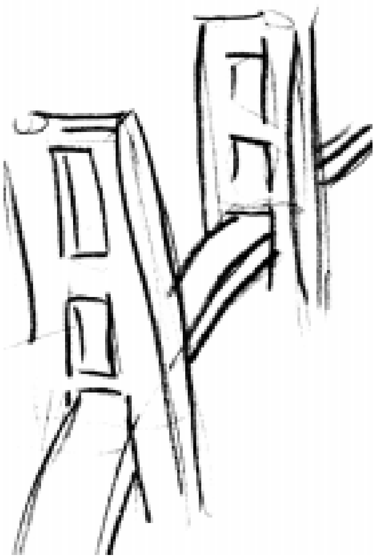
Adam Webber
Geology, UC Santa Barbara

E. A. Keller, UC Santa Barbara

The Earthquake Hazard for the Rincon Creek Anticline (RCA) and the Associated Buried Reverse Fault, Carpinteria, CA.

Personal goals: as an undergraduate geology major, I am striving to experience a broad spectrum of fields within this major, because this is my chance. These are my academic goals, and what I hope to achieve is an understanding for what I want to pursue in the future. I have a love for understanding the present and past processes of the earth, and this is what I want to focus on in the future. I am set on going to graduate school once I have received experience and an idea of what I want to pursue. Plate tectonics and geomorphology are two specific areas that I have recently studied and have gained a strong interest in. I hope to follow up on these newfound interests by gaining some experience during the summer of 1999.

Project goals: the importance of this project with respect to science and society is to gain a better understanding of the earthquake hazard that the Rincon Creek Anticline (RCA) presents to the city of Carpinteria, CA. By determining a rate of uplift and whether it was a constant rate or rapid jumps as a result of earthquake activity, the threat posed to Carpinteria can be analyzed. The RCA is a typical young fold of the Santa Barbara fold belt, and by determining localized characteristics of the structure, extrapolated information can aid in studying the larger picture of the Santa Barbara fold belt. ■



SCEC News Briefs

Many Jurisdictions in L.A. Area

SCEC Outreach Presentations to the Emergency Preparedness Commission

On June 9, 1999, Jill Andrews and Mark Benthien gave presentations to the Emergency Preparedness Commission for Los Angeles County and the cities in the area. Andrews spoke about SCEC and its outreach programs, highlighting the programs that SCEC is conducting with the city and county of Los Angeles, that include:

- A joint task force of engineers, scientists, and city and county officials to study vulnerable buildings in Los Angeles—specifically “tuck-under” or “soft story” structures such as the Northridge Meadows apartment building that collapsed in the Northridge earthquake—and nonductile concrete structures like parking garages.

- A partnership with the California Division of Mines and Geology to conduct a series of workshop to educate city officials on how to use liquefaction hazard maps. *[Ed. note: See separate article in this issue for a description of a workshop.]*

Andrews also described “The Real Meaning of Seismic Risk”—a proposed symposium that would feature lively exchanges among scientists, engineers, building officials, policymakers, insurers, developers, and the media—with the goal of encouraging public participation in and understanding of earthquake science through interactivity with SCEC.

The symposium would consist of a panel of experts with differing or opposing views who would make short presentations on urban seismic risk issues. Topics could include:

- A critique of methods used to interpret the earthquake threat
- Vulnerability of tall buildings and other structures near faults
- Whether the “life safety” design code is the best practice, given what we now know from Northridge
- Cost-benefit analyses of various retrofitting techniques and codes for new construction
- Socioeconomic impacts of earthquakes and secondary hazards in California vs. other natural hazards outside the state

A public report, with audio and video tapes of the symposium’s proceedings, would be made available through SCEC.

Andrews concluded her presentation with a request for the commission’s partnership in this project, which they granted. Chris Wright, president of the Los Angeles chapter of the Business and Industry Council on Earthquake Planning and Preparedness (BICEPP) also indicated that BICEPP will partner with SCEC on this project.

Benthien then gave a presentation on the Los Angeles Region Seismic Experiment (LARSE II), which will be conducted in October 1999. The study will use ultrasound-like images of faults, basin depths, and other features deep in the Earth’s crust to determine where earthquakes can occur and how the ground will shake as a result.

To generate the vibrations needed to form the “seismic image,” more than 100 small buried charges will detonated over a four-to-five-day period along a line from Pacific Palisades to the western Mojave Desert. To record the vibrations, 1,000 seismometers will be placed along the same line. More than 60 separate landowners will grant permission for this joint USGS-SCEC project to be located on their property.

SCEC Will Pay for Members

Stress-Triggering and Deformation Software Training Workshop

Three pieces of software in current use for studies of earthquake and fault interaction will be the subject of a two-day hands-on workshop to be held in Palo Alto on September 8-9. The goal is for the participants to develop sufficient skill that they will use the software in their own research and teach its use to others.

The course will introduce participants to Coulomb 1.0, 3D-DEF, and VISCO1D. The applications will be presented by their authors, who will walk participants through tutorials and provide simple manuals. All software and manuals will be available electronically.

To give everyone keyboard/monitor access, the workshop is limited to 45 participants. Housing will be in suites at the Schwab Residential Center of the Stanford Business School. Instruction will take place at the Mitchell Earth Sciences 20-station training center.

Participants will arrive on the afternoon of September 7, followed by a welcoming reception that evening. Other events include a barbecue on Wednesday evening and an afternoon run. The workshop is scheduled to conclude by 6 p.m. on September 9. SCEC will cover tuition, airfare within California, airport van shuttle, meals, and accommodations for its members.

Coulomb 1.0, principally written by Shinji Toda (ERI, Japan)—an evolution of GEN 1.0 by Geof King (IPG, Paris)—is a fast, menu-driven Mac program rich in graphics that performs 3D elastic dislocation and a limited number of 2D boundary element calculations of deformation and stress in an elastic half-space. Ross Stein will help Shinji Toda teach this session.

3D-DEF, written by Joan Gomberg (USGS, Memphis) and Michael Ellis (CERI, Univ. Memphis), performs elastic dislocation boundary-element calculations. The program enables a variety of boundary conditions to be applied, which makes the model quite flexible. The program and manual can be obtained via anonymous FTP to beagle.ceri.memphis.edu in the "/pub/gomberg" directory.

VISCO1D, written by Fred Pollitz (UCD) calculates the response of a spherically stratified elastic-viscoelastic medium to the stresses generated by fault slip or dike opening occurring in one of the elastic layers.

To register, or for more information, email Ross Stein at rstein@usgs.gov. Please indicate your choice of software, so sessions can be planned accordingly.

Workshop to Be Held October 3-5

Plate Boundary Observatory to Be Defined and Planned

The Plate Boundary Observatory (PBO) is a proposed facility for investigating active tectonic and magmatic processes of the Pacific/Juan de Fuca–North American plate boundary through measurements of crustal deformation. The study of plate boundary deformation is a research area that deserves increased attention from a broad spectrum of Earth scientists. Toward that end, a workshop will be convened on October 3–5 in Snowbird, Utah, to help develop the plans for such an observatory.

The PBO Steering Committee invites participation from a broad spectrum of earth scientists in a workshop to help define the PBO concept and plan for its implementation. The workshop will produce a report outlining the scientific basis for the PBO, its instrumentation requirements and deployment strategy. It will describe the ways the facility can advance earth science research and contribute to education and outreach.

The workshop will be limited to 100 participants. Each applicant to the workshop is asked to provide a brief statement of interests, including how he or she can contribute to the goals of the workshop. Partial support (air travel, hotel, and meals) will be provided by workshop funds. To apply for an invitation, see: http://www.scec.org/news/99news/pbo.html.

The chief observational requirement of the PBO is a characterization of the three-dimensional deformation field over the maximum ranges of spatial and temporal scales. The PBO should be designed to study long-term, regional tectonic processes as well as shorter-term, smaller-scale processes that may be more closely related to natural hazards, such as earthquakes and volcanic eruptions.

It is proposed that the PBO be coordinated and integrated with the proposed U.S. Array and the San Andreas Fault Observatory at Depth (SAFOD) projects as part of the EarthScope initiative being developed at NSF. In addition to advancing our basic scientific knowledge of active tectonic processes, the facility will improve seismic and volcanic hazard assessment and contribute to earth science education and outreach in the U.S.

The PBO Steering Committee consists of Yehuda Bock, Andrea Donnellan, Don Helmberger, Tom Henyey, Ken Hudnut, Gene Humphreys, Chris Marone, Meghan Miller, Bernard Minster, Barbara Romanowicz, Paul Segall, Paul Silver, Bob Smith, Seth Stein, Wayne Thatcher, George Thompson. The workshop is jointly sponsored by the NSF's Division of Earth Sciences, UNAVCO, IRIS, NASA, USGS, IGPP, and SCEC.

Moving to Private Sector

Steven Ganz Leaves WSSPC

Steven Ganz, first executive director of the Western States Seismic Policy Council (WSSPC), recently moved to the private sector, joining an Internet start-up based in San Francisco. In that move, the Earthquake Information Providers (EqIP) also loses a member of its steering committee.

A graduate of the John F. Kennedy School of Government at Harvard, Ganz's master's degree is in public policy and urban planning. Using that background and management and entrepreneurial skills during his tenure at WSSPC, he developed several outstanding programs, including a state-of-the-art Web service and a series of excellent annual meetings and workshops featuring earthquake-related public policy issues, recent research on seismic hazards in the western states, and insurance-related issues and policy recommendations.

He developed partnerships with other organizations that focus on seismic issues and research and was a technical advisor and leader among such partnerships.

Jill Andrews, SCEC outreach director, said, “We in the SCEC community will greatly miss Steve’s professional approach to bringing together people in both public and private organizations to reach consensus on earthquake-related public policy issues.

“We thank Steve for his contributions to society through association with WSSPC, and wish him all the best in his new endeavor.”

In a recent message to the earthquake research community, Ganz said of the move, “I am very sad to leave the organization, but at the same time very excited about my new opportunities. I have thoroughly enjoy working at WSSPC. I truly believe that WSSPC is an organization with a focused mission and a unique ability to continue making a significant impact in improving the means to reduce the threat of earthquake hazards.”

EQNet Developed with SCEC Participation

Omnibus Earthquake Resource Site Now Online

Chairperson Jill Andrews announced that the Earthquake Information Providers (EqIP) group has finished a full revision of the group’s Web-based catalog of earthquake-related resources. In addition, the group is submitting a proposal to NSF to continue the development of the site.

EQNet (WWW.EQNET.ORG), a project originally launched by EqIP in 1996 is intended to be a “one-stop” source for locating Internet sites related to earthquake hazards. Part of its purpose was to consolidate access to those resources, and part of it was to eliminate duplication among earthquake information providers supported by NSF.

All EqIP members have Web sites and links pages, all of which require maintenance. EQNet allows them to reduce the amount of maintenance on their own link pages by centralizing a resource they can all link to. Such a shift allows individual sites to focus on their areas of expertise.

Ultimately, EQNet may not only be a reference tool for EqIP members (and others), but also a means of promoting and attracting more visitors to all EqIP members’ Web sites.

EQNet’s webmaster, Ed Hensley, dismantled the original static pages, redesigned the structure of the site, and remounted it as an online database. At the same time, he simplified the interface, making access to the information in the database easier.

Following EqIP’s approval of the revised structure, the process of refining the site began, under the auspices of the Multidisciplinary Center for Earthquake Engineering in Buffalo:

- Refining and filling in the contents of the database
- Developing the Web interface to retain simplicity but add more capability
- Maintaining the site
- Coordinating the participation in and use of the site by EqIP members
- Marketing the site—getting it better known and more widely used

A new proposal submitted to NSF will ask for support for these continuing efforts at least through the year 2000.

With the Red Cross and Allstate

SCEC Helps Add Earthquakes to Disaster Curriculum

SCEC has joined with the American Red Cross and the Allstate Foundation in a project that will help teachers integrate disaster safety concepts into their regular lesson plans.

Announced at a news conference June 1, 1999, the Children’s Disaster Safety Curriculum will provide lessons, activities, and demonstrations that teachers can use to incorporate a hazard-related topic into other classroom subjects. To address the very real threat of earthquakes in our region, basic earth science and earthquake information will be included in the curriculum materials.

“Integrated curricula that use real-life or hands-on examples to convey lessons in science, math, language arts, and social studies are indeed the best tools for teaching today’s students,” said SCEC’s outreach director, Jill Andrews. “An issues-based integrated curriculum such as this one is especially valuable in light of the requirements of the new National Science Education Standards.”

The Children’s Disaster Safety Curriculum will be made available through local Red Cross chapters at a nominal cost. For more information, contact Rocky Lopes, Disaster Services, American Red Cross National Headquarters, at (703) 206-8805 or LOPESR@USA.REDCROSS.ORG.

Beneath the Science

By Mark Benthien

A Funny Thing Happened on the Way to the Fieldwork

For this issue of the *SCEC Quarterly Newsletter*, we requested anecdotal or humorous stories of summer field research—the memorable experiences aelong the way to the final scientific result. Here are a few of the responses.

Shirley Baher, UCLA

While in Hawaii when I was taking ESS135 A, B, C, we had a field trip to Kilauea to perform magnetic and seismic experiments. While there, we all had to perform an extra project and write a special section about it in our final report. I had chosen to prove the Curie temperature. This is the temperature at which magnetization of material goes to zero. To perform the experiment, I had a magnetometer and heat probe. I would insert the heat probe into recently formed lava, Paul Davis would read the temperature, and I would record the magnetometer readings every minute. The two measurements would be combined, a graph would be drawn, and the theory could be proven (or not proven).

The only problem with the setup was that as the lava cooled it cemented a $200 heat probe along with it. To complicate matters, there was a steady stream of lava heading our direction, and it was setting fire to the surrounding brush. So I was tugging at the heat probe with all my might, surrounded by a small brush fire and an approaching 3-ft-wide flow of lava. I finally gave up the fight and watched as the heat probe was buried even further by lava.

Sally McGill, CSU San Bernardino

I have had many interesting field assistants in the course of my paleoseismic fieldwork in southern California. I would like to pay tribute to them not only for their dedication to getting the work done but also for their cheerful spirits which made the long months in the field more enjoyable. Although I mention only two of my assistants here, I have fond memories of my time with all of them. Dawn Grant, who assisted with trench logging on the Garlock and San Andreas faults, drew beautiful, creative doodles in the margins of the logs, including a depiction of hell, located beneath the base of our trench, and upside-down people in China beneath that. Her doodles also commemorated the scattered interesting events that broke up the monotony of trench logging, such as the discovery of a scorpion in the trench one day and a sidewinder under the trailer another day.

> *We had a Mongolian guide who was usually drunk and therefore not very useful.*

Heidi Anderson assisted me with trench logging on the Garlock fault while she was an undergraduate geology major at Caltech. After graduating, she took a break from geology to study fashion design in Paris. This was an outgrowth of her summer undergraduate research project on the history of hoop skirts. As she learned more about the history of fashion she wanted to illustrate the ages of the strata in my trenches with sketches of the fashions that were popular at those times. Eventually she returned to assist me on another Garlock trench, but this time she brought a portable, hand-operated sewing machine with her, and she spent her evenings in the trailer sewing a trench-suit for herself. Heidi is now a graduate student in geology at UC Berkeley.

Shawn Larsen, Lawrence Livermore National Lab

I was on Rob Reilinger’s 1989 GPS campaign in eastern Turkey. My guide and translator was Lieutenant Alp, an army officer in the Turkish military. We also had a driver. One site was located near a small Kurdish village. We stopped at the local military command, where Lieutenant Alp discussed something with the local commander. He later told me that they were concerned about possible Kurdish rebel activity. We headed off to the GPS site at 3 o’clock the next morning. It was pitch black. Suddenly, our driver came to a complete stop as we encountered four Kurdish men standing in the road carrying automatic weapons. Worse, they opened up the door and piled into our car—a car built for four people. Oh great, I’m never going to see my cat again. Lieutenant Alp, who was purposely wearing civilian clothes to avoid being shot, started talking to them in Turkish. Meanwhile, I was silently praying in English. It’s night and I’m on a deserted road in the middle of a foreign country. I’m crammed into a small car with six other people, four of them heavily armed. As we were driving along the road, I kept using my finger to push the barrel of a machine gun away from my head. Thinking back, it’s fortunate that the movie “Pulp Fiction” hadn’t come out before this time. After we got to the site, Lieutenant Alp informed me that the army gave these men guns and asked them to protect us from possible rebel activity. It turns out that these four Kurdish men were perhaps the friendliest people I have ever met.

I was on Rob Reilinger's 1990 GPS campaign in the Imperial Valley. I usually traveled solo to my assigned sites, but this time Kenji Satake was with me to learn something about GPS. The station for the night was KANE, located near the junction of the Elmore Ranch and Superstition Hills faults. It's in the middle of nowhere, only accessible with a 4-wheel drive vehicle along a dilapidated dirt road. We headed west towards the site late in the day. It was extremely difficult to see, since we were blinded by the glare from the setting sun. As we were bouncing back and forth trying to maintain contact with the road, we could make out what appeared to be a truck and people standing around a campsite 100 yards in front of us. No problem. It's always nice to meet strangers in the middle of nowhere. We moved to within 50 yards. We were still blinded by the sun but could definitely distinguish the outline of two people. Still, something didn't quite look right. At about 25 yards I slowed and started to roll down my window. I wanted to say hello and tell these people what we were doing. But ... oh my gosh. There were a man and a woman standing there without any clothes on. Needless to say, I decided not to stop, and quickly rolled the window back up. As we passed, the woman had the decency to head for cover. On the other hand, the man stood there scratching his rear like Homer Simpson. He looked like him, too. It was not a pretty sight.

Mark Benthien, USC:
During Paul Davis' Lake Baikal Teleseismic experiment, I was stationed in Mongolia along with a team of Russian colleagues. Our seismograph stations were about 50 km apart, in areas where all dirt roads and hills look identical and finding the stations was a challenge. We had a Mongolian guide who was usually drunk and therefore not very useful, and I was a 20-year-old kid from California—so our credibility was about equal. One night we were late in arriving at the next station and had no landmarks to guide us. Our only help was a handheld GPS receiver that I had programmed with the coordinates of the station. The instrument listed the direction we were heading and the direction and distance to the station. As we approached the station, I pointed a flashlight ahead of the car so the driver (who did not speak English) could drive "cross country" in the right direction by following the spot of light on the ground ahead. This was in 1992, so GPS was new to us, and no one else in the car trusted that I would find the site. As we got close, we swerved back and forth as I adjusted our course until the driver slammed on the brakes to stop less than 2 feet from the station. I guided the team for the rest of the summer. ■

Off-Scale

authors who are not earth scientists but wish they were

"One of the Three Most Interesting Spectacles I Have Beheld"

After five years aboard the H.M.S. Beagle, Charles Darwin found himself becalmed off Chile in March of 1835 with time to write this letter to his sister.

My dear Caroline,

We now are becalmed some leagues off Valparaiso and instead of growling any longer at our ill fortune, I begin this letter to you. . . . The voyage has been grievously too long; we shall hardly know each other again; independent of these consequences, I continue to suffer so much from sea-sickness, that nothing, not even geology itself, can make up for the misery and vexation of spirit.

The papers will have told you about the great Earthquake of the 20th of February. I suppose it certainly is the worst ever experienced in Chile. It is no use attempting to describe the ruins—it is the most awful spectacle I ever beheld. The town of Concepcion is now nothing more than piles and lines of bricks, tiles and timbers—it is absolutely true there is not one house left habitable; some little hovels built of sticks and reeds in the outskirts of the town have not been shaken down and these now are hired by the richest people. The force of the shock must have been immense, the ground is traversed by rents, the solid rocks are shivered, solid buttresses 6-10 feet thick are broken into fragments like so much biscuit.

How fortunate it happened at the time of day when many are out of their houses and all active: if the town had been overthrown in the night, very few would have escaped to tell the tale. We were at Valdivia at the time. The shock there was considered very violent, but did no damage owing to the houses being built of wood. I am very glad we happened to call at Concepcion so shortly afterwards: it is one of the three most interesting spectacles I have beheld since leaving England—A Fuegian Savage—Tropical Vegetation—and the ruins of Concepcion. It is indeed most wonderful to witness such desolation produced in three minutes of time.

—Charles Darwin, 1835

Planning SCEC's Role in Clearinghouse

SCEC Scientists Conduct First Post-Earthquake Response Planning Seminar

By Jill Andrews and Mark Benthien

About 50 SCEC-affiliated researchers and students led by USGS Pasadena Scientist-in-Charge Lucy Jones met in late June to organize a new plan around the scientific objectives of a post-earthquake investigation and to discuss how those objectives could be achieved.

Following a brainstorming session, the participants broke into three groups—geology, geodetics, and seismology—to discuss the questions raised in the brainstorming session and formulate post-earthquake field experiments that would address each of those questions. At the end of the day, each group presented its conclusions, and Jones facilitated a lively session that focused on implementation methods.

The following notes outline many of the ideas brought forward in each of the breakout sessions. The results of the workshop will be synthesized into an official SCEC response plan. The group agreed it should meet again at the SCEC annual meeting to discuss the resulting plan and logistics.

Geology Group Summary (Tom Rockwell)

Following a large earthquake, geologists need to do the following:

In the first hours:

- Resolve scope of surface rupture. They would need an immediate response team that is ready to go, with necessary equipment, clearance, and transportation to resolve extent of surface rupture. This requires access to a helicopter, with direct communication back to a data collection center. Aerial photos from any source would be extremely useful. This also requires real-time epicentral information, including size, focal mechanism, etc.

- Install quadrilaterals/alignment arrays/afterslip studies, GPS, point alignments.

Collaborating When It Counts

The California Post Earthquake Information Clearinghouse

For two weeks after the January 17, 1994, Northridge earthquake, the California Office of Emergency Services (OES) Pasadena office served as the nerve center of an extensive reconnaissance effort. Every morning, earth scientists, engineers, social scientists, and public policy experts headed out to the damaged areas. After a day of looking at and studying the earthquake's effects, these experts returned to a crowded conference room in Pasadena to spend the evening sharing and reviewing their observations.

That was the first extensive operation of the California Post Earthquake Information Clearinghouse, a project of many organizations involved in earthquake studies. The clearinghouse is a unique way in which information can be exchanged among various types of investigators who come from other states and counties.

Within one day of the Northridge earthquake, clearinghouse field investigators were on site, bringing back damage reports that aided emergency response activities and focused earth science investigations. In a few days, the daily information became an impressive body of data for future analysis and use.

Clearinghouses had been organized following other California quakes. The California Division of

In the first day:

- Aerial photography of the rupture as soon as the rupture zone is established, so more detailed work of documentation, including detailed mapping and slip measurements, can begin.
- Slip measurements. There is a need to establish a common standard of quality to be followed by all participants; to perhaps establish a field mapping system complete with GPS receivers for more precise locations; to compile daily a summary of all field data at a common data collection center or clearinghouse; and to publish the data as soon as possible.
- Detailed mapping; include focus on structure complexities

There is also a need for a structured response with common standards. This should be a collaborative effort between the USGS, CDMG, SCEC geologists, and others.

Geodesy Group Summary (Ken Hudnut)

Geodesists would like to have continuous instrumentation out in the field, which would eliminate the need to rush out to the field after the event. SCIGN has not built this capability into its program. Geodesists need GPS arrays across the fault to measure displacement.

Topics of interest for such investigations:

- Coseismic
- Stress triggering (observable rate changes adjacent to other faults—co-seismic motion on neighboring faults, for example.)
    - Campaign deployments
    - Instrumenting buildings
- Long-period, long-wavelength deformations
- Various models to explain

Geodesists would rely on SCEC/USGS to coordinate efforts. A possible structure:

- SCEC: Crustal Deformation Working Group (Agnew: logistics)
- SCIGN: (Hudnut: chair scientific integration, source modeling, feedback to Agnew's group)
- USGS Menlo Park: Crustal deformation mega project (Thatcher)

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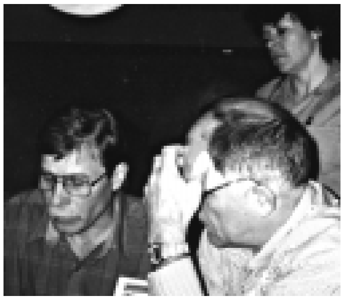

Mines and Geology (CDMG) and the USGS worked with OES and the Earthquake Engineering Research Institute (EERI) to run the modest operations out of local school gymnasiums, firehouses, community colleges, and even motels.

The value of sharing information after these events was obvious, but they also realized that the clearinghouse was an efficient way to involve and track the large number of investigators who came to the damage scene.

A few months before the Northridge earthquake, the four leading organizations were joined by the California Seismic Safety Commission (CSSC). They reached an informal agreement to establish and operate a large clearinghouse after the next major earthquake. That agreement came just in time.

Hundreds of investigators passed through the doors of the Northridge clearinghouse during its two weeks of operation. Although it as an unqualified success, it also showed the need for formal plans and the involvement of more organizations.

The Plan

Clearinghouse collaborators have been meeting quarterly since March 1996 to plan for the needs of all the involved organizations.

In summary, the plan calls for the clearinghouse to: 1) be the check-in and check-out point for all investigators and officials who arrive at the scene; 2) collect and verify perishable reconnaissance information; 3) convey that information to the planning/intelligence function of the OES Regional Emergency Operations Center; 4) provide updated damage information through daily briefings and reports; 5) track investigators in the field; and 6) perhaps even direct their movements for maximum

continued on next page

CLEARINGHOUSE *continued from previous page*

Seismology Group Summary (Ralph Archuleta)

The group discussed what experiments could be deployed to answer the scientific questions. Timing, priority, organization, and personnel were taken into account. Archuleta constructed an organizational chart that indicated coordination of data analysis and modeling, communication, and field investigations, as well as considering real-time inventory of instruments.

Scientific questions considered included:

- Site effects
    - Basin effects, basin edge, 3D structure
    - Geology + correlation to site response
    - Non-linearity (time urgency)
    - Coherency of near-field, scattering array around borehole stations
    - Ground motion and precarious rocks
    - Deep structure
- Source effects—earthquake physics (time urgency)
    - Near field (source) recordings [time urgent]
    - Source properties (temporal changes)
    - Rupture dynamics
    - Rupture nucleation? (good rock sites)
    - Rupture stopping?
    - Subsurface structure
    - Fault zone trapped waves (fault complexity)
    - Where is the fault?
    - Stress triggering (modeling)
- Crustal structure? Refraction

Other issues discussed by the entire group:

- The need for cell phones and whether they are dependable in a post-earthquake setting
- Walkie-talkies
- The need to construct a Web page that could be used as a communications vehicle and that is password protected.
- The need for ID cards, letters of permission to enter affected areas
- The need to interface with California's OES and its technical clearinghouse
- The need to invite SCEC researchers to future technical clearinghouse meetings
- The need to recruit volunteers to continue the science plan effort
- The need to conduct exercises based on scenario earthquakes
- The need to identify funds for a post-earthquake scenario ■

COLLABORATING *continued from previous page*

coverage with minimal disruption to residents.

In the few years since Northridge, the technology for capturing data has been vastly improved, and what was a comparatively primitive system in 1994 is now a networked geographic information system capable of tracking the investigators as well as their findings.

Within the clearinghouse management group, CDMG and USGS are responsible for conducting seismologic and geologic assessments of earthquakes. EERI has a charter from the National Science Foundation to investigate the structural and social effects of all major earthquakes in the U.S. and abroad. The CSSC is the main seismic policy body in the state, recommending new legislation and regulations to minimize earthquake losses. OES coordinates all the emergency planning and response activities in the state.

Besides the members of the management group, ten other organizations have signed on as participants in the clearinghouse plan:

Applied Technology Council

California Institute of Technology

California Universities for Research in Earthquake Engineering

Federal Emergency Management Agency, Region IX

National Aeronautics and Space Administration

Pacific Earthquake Engineering Research Center

Southern California Earthquake Center

Structural Engineers Association of California

Technical Council on Lifeline Earthquake Engineering

UC Berkeley Seismological Laboratory

Triggering a Clearinghouse

An earthquake in an urban area will trigger establishing a clearinghouse when the quake is damaging and has a magnitude of 6.0 or above. A clearinghouse may be established under other conditions if recommended by CDMG staff during initial field surveys following an earthquake.

A federal disaster declaration is not necessary to activate the clearinghouse, but the clearinghouse will always be activated when there is a federal disaster declaration.

In the first 24 hours after a serious quake, the OES region in which the earthquake strikes will provide, or work with other governmental units to arrange for, the clearinghouse space.

The duration of the clearinghouse operation depends on the extent of the damage and the length of the response period. While there is still a need for information to support response activities, or perishable data to be gathered, the field investigators will survey the damaged area. ■

Adapted from an article published in California Geology, March/April 1999, by Sarah K. Nathe.

Teachers Sacrifice Yet Another Weekend

By Jill Andrews

I used to think I wanted to be a K-12 teacher. I thought it would be an easy career—teaching straight out of texts to well-behaved students who are motivated and eager to learn, with lots of time to rest, read, and travel during the summer. I held that idyllic but erroneous view for years until I began spending a weekend each quarter with a group of ridiculously busy, hard-working teachers and teacher trainers who are advising our Web authors as they develop SCEC and SCIGN online educational modules.

As I sat down to write a report on our second SCEC Outreach/DESC-Online Advisory Team Workshop, held in June, I started thinking about what it means to give up a weekend. Much of a teacher's evenings and weekends are already filled with planning, grading, training, or researching. Why give up four more weekends to help with someone *else's* project?

DESC-Online workshop participants take a break from the long hours of curriculum development: (l to r) Phil LaFontaine, Meridith Osterfeld, Jill Andrews, Katrin Hafner, Cindy Anderson.

Their answer: it's for a good cause. Teachers are greatly in need of well-constructed, user-friendly earth-science curricula aligned with the national standards. Our DESC-Online project offers an opportunity for teachers to collaborate with scientists to produce a first-rate Web-based teaching and learning tool for middle school and high school students.

Over the course of those two days in June, we immersed ourselves in learning what it takes to create and flesh out a storyline for a middle school version of our two existing modules—"Investigating Earthquakes through Regional Seismicity" (www.scecdc.scec.org/module) and "Exploring the Use of Space Technology in Earthquake Studies" (scign.jpl.nasa.gov/learn). Here's how we did it.

Midnight, Friday, June 4: All the preparations for the workshop were complete. SCEC staff members and Web authors all arrived hours earlier at the motel near UC Santa Barbara, but so far none of the teachers were there, and I was worried. Did they have the right date? Since it was so late, there was nothing to do but go to bed and hope they arrived by morning.

Had I known these people better, I wouldn't have worried. Having spent all day in a training workshop in Orange County, they started out about 10 p.m. and drove from Irvine to Santa Barbara. Although Meridith Osterfeld, Phil LaFontaine, Cindy Anderson, and Don Whisman got only a few hours' sleep, they were up

DESC-Online Background

In early 1998 SCEC launched a formal review and testing of its educational materials under development, with a commitment to bringing the Web-based products online as quickly as possible. The scientific review, now complete, focused on scientific accuracy and pedagogical effectiveness. At the same time, we assembled a group of educators to work with our Web authors to test the existing modules and help us create a new module for middle and high school students. The group, called the Development of Earth Science Curricula (DESC) Online Advisory Group, has met four times to date (with another three weekends scheduled through the remainder of SCEC's fiscal year) and has completed a design and storyline for the new module. Between workshops, group members work and communicate via the Internet to further develop portions of the modules to present at subsequent workshops. The Web authors use input from the advisors and add graphics, illustrations, animated text, etc. to make the material dynamic and interesting for both teachers and students.

Meridith Osterfeld—
Regional Director, K-12 Alliance

Phil LaFontaine—
Regional Director, K-12 Alliance

Cindy Anderson—
Regional Director, K-12 Alliance & 6th grade teacher at Vista Unified School District

Don Whisman—
Staff Developer, K-12 Alliance & 8th grade teacher at Tierra Del Sol Middle School

Ursula Sexton—
the first elementary teacher to win the Presidential Award

early and ready for work on Saturday. Ursula Sexton, the other member of the group, arrived later that morning.

The ABCs of the 4As

9 a.m., Saturday, June 5: After introductions, Phil gave the group a clear explanation of the all-important storyline, the basis for constructing a usable curriculum. The standards, he explained, include *what* should be taught but not *how* to teach it. Their "4A" model was developed, he explained, to aid teachers in constructing a storyline that addresses the "how" and the "what."

In the 4-A model, the first "A" stands for "Alignment"—identifying what teachers think students should know, called "prethinking" the learning process. Using earthquakes as an example, we came up with the following ideas:

Earthquakes happen in different areas for different reasons.

Earthquakes have consequences, but with mitigation, we can change these.

Earthquakes reshape the earth.

Earthquakes are the result of what the earth is doing—constantly changing. (This concept is known as a "Big Idea.")

Earthquakes are measurable.

This exercise leads to statements of what *we* think students should know.

The second "A"—"Augmentation": This step asks the teacher to decide what makes sense to students. What tools do students need, what "hooks" should exist in a package that will make them remember what they learn. Research shows that most students retain information if it is conveyed in the format of a story—especially if it's a story that is relevant to the student's life.

During the process of augmentation, a teacher develops a storyline, starting with the "Big Idea" and moving through general concepts, appropriate levels of subconcepts. Each component leads the student to the next. If the story makes sense and is a memorable one, it is easily recalled, along with the facts related to the topic. A teacher's goal is to construct a storyline that students can learn from, that is rigorous, and that meets the requirements of the standards.

The third "A" stands for "Accessibility." All students in California, for example, should have access to knowledge. This requirement gives rise to "Decision Point Assessment"—i.e., if some students don't "get it," the teacher has to figure out what needs to be done to help those students learn.

The fourth "A" is "Assessment," which is conducted before, during, and after lessons. A lesson that covers waves, for example, should include teachers' background information on the topic—called "front loading" the concepts—so teachers can anticipate students' questions. Assessment during and after is equally important to ensure that students are understanding and retaining the knowledge.

A Portion of the Middle School Module

Unifying Concept: Earth processes create changes that are observable and measurable over time.

Module Concept: The Earth changes through a process called "plate tectonics."

Subconcept #1: Observations provide evidence of changes in the Earth.

- Observations are made using a variety of tools.
- Observations of local land forms and/or local structures/features and formation of a hypothesis of how it came to be.
- A compilation of detailed, local observations leads to a larger/regional/global picture.
- The present is a key to the past. Patterns of observations have helped to build a unifying theory called "plate tectonics."

Subconcept #2: Plate tectonics explains important features of the Earth's surface and major geologic events.

- The Earth is layered (clues on the surface provide clues to what's below).
- Lithospheric plates move at the rate of centimeters per year in response to movement in the mantle.
- Major geologic events result from these plate interactions and motions.

Subconcept #3: Major geologic events impact society.

Getting Down to Sixth-Grade Level

Noon: Following the 4A overview, Meridith and Cindy led the group through a "Star Lab" activity to demonstrate how some middle school students learn about tectonics and the Earth's interior. This meant that we first had to imagine ourselves as sixth graders (not hard for some of us), crawl inside the giant air-filled sphere they had brought with them, and view a depiction of the Earth's tectonic plates with the aid of a laser disc that projected an image on the inner skin of the sphere.

After viewing the plates in motion, we moved to a laboratory where we performed an experiment that illustrated the processes at work in the Earth's interior. As "students," we were asked to explain what we thought was occurring in our liquid-filled beakers as we dropped dye into the liquid and moved a burner underneath to heat the liquid. Most of us figured out that we were learning about the process involved with the Earth's core heating the magma, causing convection and thus tectonic activity. We were told that when students are in a lab setting, learning the "hands-on" way as we were doing, they become completely engrossed in the process and behavior problems are nearly nonexistent.

After our experiment, we viewed a video that used animated graphics and film footage to help the teachers explain what we had just seen, touched, and learned. By the time we were finished (the whole process took about two hours), we were ready to think on the level of a sixth grader—a most effective way to create a science-based storyline.

Putting the Pieces Together

2:00 p.m.: Facilitated by Meridith, the group began the time-consuming but rewarding process of creating an earth science storyline, Big Idea, concepts, and subconcepts for a new middle school module. The product will be an 8- to-12-week segment of 32 50-minute lessons.

Finishing the Job

Sunday, June 6: After dinner and a late-evening Saturday filled with talk about our work, homes and hobbies, we were tired when Sunday morning rolled around, but were ready to finish what we'd begun. Our goal was to provide the Web authors with enough information to start the process of reworking our community-college level modules into a product appropriate for middle school. Jim Russell, vice president for education and outreach for the Institute of Business and Home Safety was a welcome observer who gave us the societal impact point of view. The group continued to flesh out the outline and finished in time for lunch together before parting company.

Driving home late that afternoon, I was pleased with what we had accomplished and grateful to those already overcommitted teachers for spending yet another weekend improving the nation's science education curricula. All of us—scientists, parents, and students alike—can be thankful for that kind of dedication. ■

Calendar

August 1999

5-8 SCEC Intern Colloquium

9-12 Ninth International Conference on Soil Dynamics and Earthquake Engineering (SDEE '99). Sponsors: Institute of Solid Earth Physics, University of Bergen, Norwegian Society for Earthquake Engineering. Bergen, Norway. Contact: K. Atakan, email: sdee99@ifjf.uib.no; www.ifjf.uib.no/seismo/sdee99.html.

15-30 Field trip to western Turkey: Extensional tectonics, modern and historical earthquake surface breaks and archaeoseismology. 90 (212) 285 6299; 90 (212) 285 6210, fax; ealtunel@ogu.edu.tr or barka@itu.edu.tr

31–Sept 2 Autonomous Data-Gathering Systems in Extreme Environments, Jet Propulsion Laboratory, Pasadena, CA. Abstract and reg. deadline: July 15. Contact: Andrea Donnellan, JPL, 818-354-4737, andrea@cobra.jpl.nasa.gov; http://geodynamics.jpl.nasa.gov/antarctica.

September 1999

6-9 Western States Seismic Policy Council 21st Annual Conference. Santa Fe, New Mexico. Contact: WSSPC, (415) 974-6435; fax: (415) 974-1747; email: wsspc@wsspc.org.

7-9 Stress Triggering and Deformation Software Training Workshop. For information, see www.scec.org/news/99news/stress.html.

20 USC—Davidson Conference Center: Science Seminar: HAZUS Demonstration and Discussion; Active faulting and earthquake hazards in the Los Angeles metropolitan area.

27-29 SCEC Annual Meeting, Palm Springs, CA. Contact SCEC, 213/740-5843 or see www.scec.org.

26-30 California Emergency Services Association Annual Conference and Training: "Defining 21st Century Emergency Management, Managing Reality vs. Perceptions in a Media World." Palm Springs, CA. Contact: Wendy Milligan, (805) 644-0899; fax: (850) 642-2883; email: scesamgr@aol.com.

October 1999

1-Nov 15 Los Angeles—LARSE II Experiment. Interested parties and volunteers needed. Contact Mark Benthien, SCEC Outreach.

3-5 Snowbird, Utah—Plate Boundary Observatory (PBO) Workshop: to apply, see http://www.scec.org/news/99news/pbo.html.

13 California Post-Earthquake Information Clearinghouse Meeting, Oakland, CA. For more information, contact T. Toppozada, CDMG Sacramento.

27-28 Sixth Annual Congress on Natural Hazard Loss Prevention. Sponsor: Institute for Business and Home Safety. Memphis, TN. Contact: (617) 292-2003; fax: (617) 292-2022; email: info@ibhs.org; www.ibhs.org.

27-29 Second Meeting on Seismology and Seismic Engineering of Mediterranean Countries—Sismica99. Faro, Portugal. Tel/fax: +351 (0)89 803561 (ext. 6545); fax: +351 (0)89 823539; email: seismic99@ualg.pt; www.ualg.pt/est/adec/sismica99/sismica99gb/index.htm.

November 1999

18 USC—Science Seminar. Topic: To be announced

December 1999

13-17 Fall American Geophysical Union meeting, San Francisco, CA. See http://earth.agu.org/meetings/sm99top.html.

16 USC—Science Seminar. Topic: To be announced

January 2000

20 USC—Science Seminar. Topic: To be announced

30-Feb 4 12th World Conference on Earthquake Engineering. Auckland, New Zealand, P.O. Box 2009, Auckland, New Zealand;
tel: 64-9-529 4414;
fax: 64-9-520 0718;
email: 12wcee@cmsl.co.nz;
www.cmsl.co.nz/12wcee;
also see www.eeri.org/Meetings/12WCEE.html.

Phone 213/740-1560 for SCEC Outreach
Phone 213/740-5843 for General Information
Fax 213/740-0011 Email: scecinfo@usc.edu

Publications

The following is a list of recent publications based on SCEC-funded research. SCEC authors must obtain SCEC contribution numbers for all papers 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, complete the online form at www.scec.org/research/scecnumber.html, which requires 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.*

277. McGill, S. F. and C. M. Rubin, Surficial Slip Distribution on the Central Emerson Fault During the 28 June 1992 Landers Earthquake, *Journal of Geophysical Research*, 104, no. B3, pp. 4811-4833, 1998.

384. Madariaga, R., K. Olsen, and R. Archuleta, Modeling dynamic rupture in a 3D earthquake fault model, *Bulletin of the Seismological Society of America*, 88, pp. 1182-1197, 1998.

391. Day, S. M., Efficient Simulation of Constant Q using Coarse-Grained Memory Variables, *Bulletin of the Seismological Society of America*, 88,1051-1062,1997.

396. Jackson, D. D. and Y. Y. Kagan, VAN method lacks validity, EOS, *Transactions of the American Geophysical Union*, 79, no. 47, pp. 573 and 579, 1998.

Varotsos and colleagues (the VAN group) claim to have successfully predicted many earthquakes in Greece. Several authors have refuted these claims, as reported in the May 27, 1996, special issue of *Geophysical Research Letters* and a recent book, *A Critical Review of VAN* [edited by Lighthill, 1996]. Nevertheless, the myth persists. In the letter we summarize why the VAN group's claims lack validity.

407. Bazzurro, P., and C. A. Cornell, Disaggregation of Seismic Hazard, *Bulletin of the Seismological Society of America*, 89, no. 2, pp. 501-520, 1999.

408. Hearn, E. H., and E. D. Humphreys, Kinematics of the Southern Walker Lane Belt and Motion of the Sierra Nevada, California, *Journal of Geophysical Research*, 103, pp. 27033-27049, 1998.

Deformation in the southern Walker Lane Belt region of the southwestern Great Basin accommodates significant portions of both Pacific-North America transform motion and Basin and Range extension. However, apparent kinematic inconsistencies between geodetic and fault slip data in this region make it difficult to understand the nature of the interaction between these processes. Kinematic modeling of the region in applied to this region in a manner that enforces kinematic consistency and simultaneously includes fault geometry and slip rate data, GPS survey data, and VLBI/VLBA site velocity data. A model is found that is consistent with the set of available data, and this model differs significantly from prior models for the region. Our model has the Sierra Nevada block, which bounds the Great Basin to the west, moving N49W +-1 at a rate of 12.7 +-0.5 mm/yr, with only minor amounts of counterclockwise rotation. Garlock fault slip is a consequence of the relatively great westerly motion of the Sierra Nevada, which lies immediately north of the Garlock Fault. We also find that the southern Great Basin adjacent to our study area moves westward at a rate of about 2.5 mm/yr, which is slower than the velocity in the central Great Basin.

412. Ward, S. N., On the Consistency of Earthquake Moment Rates, Geological Fault Data, and Space Geodetic Strain: The United States, *Geophysical Journal International*, 134, pp. 172-186, 1998.

New and dense space geodetic data can now map strain rates over continental-wide areas with a useful degree of precision. Stable strain indicators open the door for space geodesy to join with geology and seismology in formulating improved estimates of global earthquake recurrence. In this paper, 174 GPS/VLBI velocities map United States' strain rates of <0.03 to >30.0 x10-8/y with regional uncertainties of 5 to 50%. Kostrov's formula translates these strain values into regional geodetic moment rates. Two other moment rates, M_seismic and M_geologic extracted from historical earthquake and geological fault catalogs, contrast the geodetic rate. Because M_geologic, M_seismic and M_geodetic derive from different views of the earthquake engine, each illuminates different features. In California, ratios of M_geodetic to M_geologic is 1.20. The near consistency points to the completeness of the region's geological fault data and to the reliability of geodetic measurements there. In the Basin and Range, Northwest and Central United States, both geodetic and seismic greatly exceed geologic. Of possible causes, high incidences of understated and unrecognized faults most likely drive the inconsistency. The ratio of M_seismic to M_geodetic is everywhere less than one. The ratio runs systematically from 70-80% in the fastest straining regions to 2% in the slowest. Although aseismic deformation may contribute to this shortfall, I argue that the existing seismic catalogs fail to reflect the long-term situation. Impelled by the systematic variation of seismic to geodetic moment rates and by the uniform strain drop observed in all earthquakes regardless of magnitude, I propose that the completeness of any seismic catalog hinges on the product of observation duration and regional strain rate. Slowly straining regions require a proportionally longer period of observation. Characterized by this product, gamma distributions model statistical properties of catalog completeness as proxied by the ratio of observed seismic moment to geodetic moment. I find that adequate levels of completeness should exist in median catalogs of 200 to 300 year duration in regions training 10-7/y (comparable to southern California). Similar levels of completeness will take more than 20,000 years of earthquake data in regions straining 10-9/y (comparable to southeastern United States). Predictions from this completeness statistic closely mimic the observed M_seismic to M_geodetic ratios and allow quantitative responses to previously unanswerable questions such as: "What is the likelihood that the seismic moment extracted from a earthquake catalog of X years falls within Y% of the true long term rate?" The combination of historical seismicity, fault geology and space geodesy offers a powerful tripartite attack on earthquake hazard. Few obstacles block similar analyses in any region of the world.

413. Trecker, M. A., L. D. Gurrola and E. A. Keller, Oxygen Isotope Correlation of Marine Terraces and Uplift of the Mesa Hills, Santa Barbara, California, U.S.A., Late Quaternary Coastal Tectonics (probably) *Spec. Publ. Geol. Soc. London*, 146, pp. 57-59, 1998.

Resolving marine terrace chronologies is critical for determining uplift rates along tectonically active coastlines. Unfortunately, lack of suitable dating materials often makes it difficult to establish the chronology. We present here oxygen isotopic data from 21 shells of Olivella biplicata from four marine terraces in the Santa Barbara and Ventura area located in southern California, U.S.A. Uranium series analysis of two fossil corals Balanophyllia elegans from two Santa Barbara area marine terraces yielded ages of 47 ka +/- 500 yrs and 70 +/- 2 ka (oxygen isotope stage 3a and 5a, respectively) Gurrola et al. 1996 and 1997). Olivella shells from these dated calibration points yield average values of 1.117" and 0.627" respectively. Mollusks from undated terraces hypothesized to be of the same age yielded average values of 1.010" and 0.751" respectively. The data indicate that stable oxygen isotopic signatures preserved in marine terrace mollusks can provide a useful tool for correlating undated terraces to those of known age, as well as for correlating terraces across faults and folds. Using isotopic data coupled with a U-series dated wave-cut platform we calculate a rate of uplift ranging from 0.62 +/- 0.03 mm/yr (where the elevation of the first emergent terrace is 41 m) to 0.54 +/- 0.05 mm/yr (where the first emergent terrace is at 36 m) for marine terrace flights preserved on the Mesa hills anticline located in the city of Santa Barbara, California.

414. Vidale, J. E., D. C. Agnew, M. J. S. Johnston and D. H. Oppenheimer, Absence of earthquake correlation with Earth tides; an indication of high preseismic fault stress rate, *Journal of Geophysical Research*, 103, pp. 24567-24572, 1998.

417. Bowman, D. D., G. Ouillon, C. G. Sammis, A. Sornette and D. Sornette, An Observational Test of the Critical Earthquake Concept, *Journal of Geophysical Research*, 103, no. 24, pp. 359-372, 1998.

We test the concept that seismicity prior to a large earthquake can be understood in terms of the statistical physics of a critical phase transition. In this model, the cumulative seismic strain release increases as a power-law time-to-failure before the final event. Furthermore, the region of correlated seismicity predicted by this model is much greater than would be predicted from simple elasto-dynamic interactions. We present a systematic procedure to test for the accelerating seismicity predicted by the critical point model and to identify the region approaching criticality, based on a comparison between the observed cumulative energy (Benioff strain) release and the power-law behavior predicted by theory. This method is used to find the critical region before all earthquakes along the San Andreas system since 1950 with M 6.5. The statistical significance of our results is assessed by performing the same procedure on a large number of randomly generated synthetic catalogs. The null hypothesis, that the observed acceleration in all these earthquakes could result from spurious patterns generated by our procedure in purely random catalogs, is rejected with 99.5% confidence. An empirical relation between the logarithm of the critical region radius (R) and the magnitude of the final event (M) is found, such that log R µ 0.5 M, suggesting that the largest probable event in a given region scales with the size of the regional fault network.

419. Harris, R. A. and R. W. Simpson, Suppression of Large Earthquakes by Stress Shadows—A Comparison of Coulomb and Rate-and-State Failure, *Journal of Geophysical Research*, 103, pp. 24439-24451, 1997.

420. Harris, R. A., Stress Triggers, Stress Shadows, and Implications for Seismic Hazard, *Journal of Geophysical Research*, 103, pp. 24347-24358, 1997.

429. Ward, S. N., On the Consistency of Earthquake Moment Release and Space Geodetic Strain Rates: Europe, *Geophysical Journal International*, 135, pp. 1011-1018, 1998.

In this article, 141 VLBI/SLR/GPS velocities map European strain rates from <0.09x10^-8/y to >7.0x10^-8/y with regional uncertainties of 20 to 50%. Kostrov's formula translates these strain values into regional geodetic moment rates M_geodetic. Two other moment rates, M_seismic extracted from a 100-year historical catalog, and M_plate taken from plate-tectonic models, contrast the geodetic rates. In Mediterranean Europe, the ratios of M_seismic to M_geodetic stand between 0.56 and 0.68. In Turkey the ratio falls to 0.18. Although aseismic deformation may contribute to this deficit, the magnitudes of the shortfall coincide with the variations expected in 100-year catalogs.

431. Xu, H. S. M. Day, and J. B. Minster, Model for Nonlinear Wave Propagation Derived from Rock Hysteresis Measurements, *Journal of Geophysical Research*, 103, pp. 29915-29929, 1998.

We develop a method for modeling nonlinear wave propagation in rock at intermediate strain levels, i.e., strain levels great enough that nonlinearity cannot be neglected, but low enough that the rock does not incur macroscopic damage. The constitutive model is formulated using a singular-kernel endochronic formalism, and this formulation is shown to satisfy a number of general observational constraints, including producing a power law dependence of attenuation (Q-1) on strain amplitude. Once the elastic modulus is determined, and a second parameter fixed to give Q-1 linear in the strain amplitude, the model has 2 remaining free parameters. One of these represents cubic anharmonicity, and we set in to agree with laboratory observations of harmonic distortion. The other parameter controls the amount of hysteresis, and it is set to approximate stress-strain curves measured in laboratory uniaxial stress experiments on Berea sandstone by Boitnott and Haupt. The constitutive equations, though fundamentally nonlinear and rate-independent, have a superficial, formal resemblance to viscoelasticity, which we exploit to produce an efficient, stable numerical algorithm. We solve 1D wave propagation problems for this constitutive model using both finite difference and pseudospectral methods. These methods are shown to reproduce, to high precision, analytical results for quasi-harmonic wave propagation in a nonlinearly elastic medium.

Application of the Berea sandstone model to quasi-harmonic wave propagation shows several departures from results obtained with nonlinear elasticity. The Berea model shows more rapid decay with distance of the fundamental frequency component, due to nonlinear, amplitude-dependent attenuation, than does nonlinear elasticity. The Berea model also shows enhanced excitation of the order 3 harmonic, in agreement with laboratory observations. In addition, the growth with propagation distance of the harmonics of the source excitation shows a saturation, relative to the nonlinear elasticity results. This behavior reflects the competing effects of amplitude growth via energy transfer from the source frequency, and energy dissipation due to hysteresis, the dissipation increasing as the harmonic amplitude grows. In additional numerical experiments, we find that a two-frequency source function generates harmonics with frequencies which can be expressed as linear combinations of integer multiples of the two source frequencies, in agreement with published laboratory results for other solids.

434. Sato, T. and H. Kanamori, Beginning of earthquakes modeled with the Griffith's fracture criterion, *Bulletin of the Seismological Society of America*, 89, no. 1, pp. 80-93, 1998.

We present a source model for the beginning of earthquakes based on the Griffith's fracture criterion. The initial state we choose for this model is a critical state of pre-existing circular fault, which is on the verge of instability. After the onset of instability, the fault grows with a progressively increasing rupture speed, satisfying the condition of fracture energy balance at the crack tip. We investigate the difference in rupture growth patterns in two classes of models, which are considered to represent end-member cases. In the first model (Spontaneous Model), we assume that the surface energy varies smoothly as a function of position in the crust. In this model, faults with small initial dimensions grow in the medium with small surface energy, and those with large initial dimensions, in large surface energy. The rupture velocity increases progressively until it reaches its limiting velocity. The synthetic velocity seismogram at far-field shows a weak initial phase during the transitional stage. The time taken to reach the limiting velocity is proportional to the initial length of pre-existing fault. Therefore the duration of the weak initial phase scales with the initial length of fault. In the second model (Trigger Model), we envisage that there are many pre-existing faults in the crust with various length. These faults are stable because they encounter some obstacle at their ends (e.g. fault segmentation, strong asperity etc). This situation is modeled with a local increase in the surface energy near the ends of fault. An earthquake is triggered when the obstacle is suddenly removed (i.e., sudden weakening) or the stress is suddenly increased locally to overcome the obstacle. Once an earthquake is triggered then the fault growth is governed by the ambient surface energy. In this model, the rupture speed attains its limiting velocity almost instantly. The synthetic velocity seismogram at far-field shows an abrupt, linear increase in amplitude without the weak initial phase that appears in the Spontaneous Model. The Spontaneous Model is characterized by a small trigger factor and the Trigger Model by a large trigger factor, where the trigger factor is defined as a fractional perturbation of the surface energy at the ends of fault relative to the ambient surface energy. Thus, the seismic initiation phase with and without the slow initial phase can both occur depending on the trigger factor. The variability in the observed seismic initiation phase may represent a variation of surface energy (strength) distribution surrounding the pre-existing cracks. No simple model can explain the scaling relation between the nucleation moment and the eventual size of earthquake.

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Palos Verdes Peninsula—Written for teachers and students as well as the general public, this guide offers a lively narrative on a number of sites at which to observe fossils, rock structures, and faults. Two foldout maps are included.

Palos Verdes Fault—This field trip guide is designed for engineers, geotechnical professionals, and earth scientists. Unlike the broad information provided in the Palos Verdes Peninsula field trip guide, this guide focuses on the Palos Verdes fault. Included is a discussion of the fault as a whole as well as information pertaining to the many sites along the route.

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

Caltrans/City of Los Angeles/County of Los Angeles Task Reports

The Task H-1 report describes improved empirical models for scaling the amplitudes of earthquake response spectra for the southern California region. (3 volumes)

The Task H-2 report focuses on potential destructive earthquakes along the Hollywood and Santa Monica faults.

The Task H-3 report examines the use of weak motion amplification factors for microzonation, and the relationship between weak and strong motion amplification.

The Task H-4 report describes the development of empirical models for scaling duration of strong ground motion by utilizing regression analyses of recorded data.

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The Task H-8 report describes the use of geotechnical data to reassess and improve the Los Angeles geological database used to develop liquefaction potential maps. This report complements Task H-5.

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