Quarterly Newsletter
Volume 4, Number 1

Southern California Earthquake Center

3
Precarious Rocks Record Seismicity

6
Interview: Jean-Bernard Minster

12
Research in Progress: San Joaquin Hills

16
SCEC News Briefs

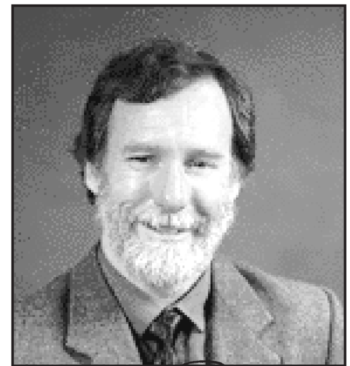
21
1998 SCEC Research Program and Projects

26
Feature: Charles Richter

From the Center Directors . . .

Earth Science Research Needed for Earthquake Hazard Reduction

Thomas H. Henyey
Center Director



David D. Jackson
Science Director

As the science director of SCEC, I am often asked what earthquake science can do to reduce earthquake hazards and what research tasks are most important in this endeavor. The statement below addresses those questions. Comments are welcome. Please bear in mind that this statement is not meant to represent the entire SCEC research agenda. The statement addresses a practical problem—how to protect lives and property. The SCEC research agenda must address this problem while also fostering fundamental discovery that may or may not reduce hazards. Furthermore, the practical agenda below must involve national and international partnerships well beyond the SCEC boundary. —David D. Jackson

Effective reduction of earthquake hazards requires assessment of the hazard, identifying options for protecting people and structures, assessing the effectiveness of these options, prioritizing mitigation, and selling the program. First, we must attack the elements of the hazard that can be mitigated most economically. This is where the earth sciences play an essential role. Predicting times of individual earthquakes does not appear possible in the foreseeable future, so an effective approach to risk reduction must focus on long-term earthquake potential. To fulfill their role, earth scientists must answer three important questions.

Where will earthquakes occur and how large could they be?

Studies of active faults, records of past earthquakes, and measurements of distortion of the earth's crust help to define earthquake potential. The greatest need in earthquake hazard assessment is for basic data on faults and earthquakes. We need mapping and seismic imaging of faults; fault trenching to find dates and sizes of prehistoric earthquakes; seismic recordings of small and large earthquakes; and strain rate measurements with GPS and other techniques.

A critical need is to test ideas about earthquakes. For example, the size of future earthquakes may be limited by readily measured quantities like fault length. The earthquake potential may also be strongly affected by stresses from previous large earthquakes. We cannot adequately test these ideas locally because large earthquakes are so rare. An effective strategy must include international cooperation so that earthquakes everywhere on earth can be used to test the most important hypotheses.

What level of ground shaking, landslides, and liquefaction will these earthquakes cause?

The effects of earthquake shaking depend on the size and complexity of fault rupture, reverberation and focusing of seismic waves, and the local soil conditions. Earth scientists contribute greatly to safety by identifying site characteristics that contribute to damage, independent of the particulars of earthquakes.

Young sedimentary sections, margins of sedimentary basins, and other topographic features have been sites of abnormally severe effects in recent earthquakes. However, we lack a comprehensive theory that explains why, and we cannot yet distinguish well between site effects and unique features of earthquake rupture. Some answers will come from modeling the reverberation of seismic waves in sedimentary basins. But we need many recordings of individual earthquakes as well as recordings of many earthquakes at individual sites to distinguish between source and site effects.

Getting the necessary data will require new seismographs and future earthquakes. We can accelerate our learning by international cooperation. Helping to install modern seismic arrays in Japan, New Zealand, and other hotspots could bring us needed data sooner. We cannot afford to waste a single earthquake.

What is the relationship between ground shaking and damage to structures?

Seismic wave trains are made complex by reverberations within the crust. To develop and prioritize protective measures, we must know how long and how strong the waves must be to cause damage.

Progress requires close cooperation between earth scientists and engineers. Our understanding suffers from lack of specific knowledge of ground motion at sites where damage has occurred. We have settled for overly simple descriptions of ground motion, such as Modified Mercalli Intensity or peak horizontal acceleration. Damage also depends on the duration of strong shaking, its frequency content, etc.

To understand damage better, seismologists must provide a more complete description of motion, including a "time history" or seismogram, at sites where damage has occurred but no recordings were made—i.e., interpolate readings from seismograph locations to the locations of structures.

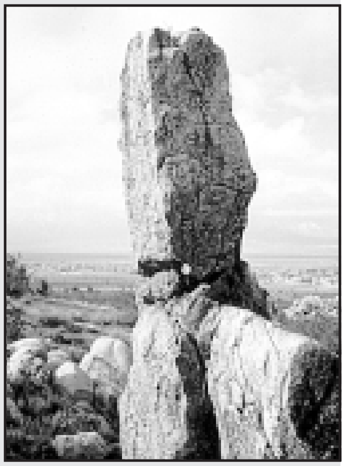
An adequate solution requires new data on ground shaking and building response. Research is needed to develop computer models of ground shaking, test them against existing data, and apply them to estimate the ground motion that caused damage. A strategy to estimate ground motion and building response together will vastly improve our ability to optimize and sell an earthquake mitigation strategy.

Precarious Rocks May Help Estimate L.A. Basin's Seismic Hazard

By Jill Andrews

What's a Precarious Rock?

Out in the field, the initial judgment of precariousness is relatively easy: the rocks look as though they could be toppled by relatively low accelerations. In addition, they have to be in a position so that once toppled, they would not return to an unstable position with further shaking. In most cases, the rocks are also not the result of having recently fallen downslope or accidentally ending up where they are. Quantitatively, the acceleration required to topple a rock is roughly proportional to the tangent of the angle between vertical and a line from the center of mass to the base rocking point, multiplied by the acceleration of gravity (Wiechert, 1994).



James Brune's 1998 SCEC-funded research project, "Study of the Toppling Accelerations of Precarious Rocks on a Profile Perpendicular to the San Andreas Fault for Constraining Strong Motion Attenuation Relationships for Great Earthquakes," is an innovative approach to earthquake hazard assessment. His studies of precariously balanced rocks may provide important quantitative constraints on ground motion from large earthquakes in the last few thousand years (also see Brune, 1994).

In several areas of Nevada and California there are many precariously balanced rocks—rocks that have been in place for centuries and could be knocked down by earthquake ground motion with peak accelerations of about 0.2 g (20 percent the force of gravity) or less. Significant damage to older buildings begins at this level.

For comparison, the Southern California Earthquake Center produced a hazard map showing the number of times per century the shaking from earthquakes will exceed 20 percent the force of gravity. Cast in probability terms, the same analysis predicts that the greater southern California region should experience a magnitude 7.0 or greater earthquake about five times each century.

Since the most recent great strike-slip earthquakes along the San Andreas fault occurred in 1857 and 1906, before the invention of strong motion instruments, estimates of the earthquake hazard for California depend on extrapolation from data gathered on much smaller earthquakes—and are therefore uncertain. Various hazard maps for California (including the SCEC "Phase II" hazard map) depend on these uncertain extrapolations, and according to Brune, there are no known field methods other than the use of precarious rocks to test these extrapolations.

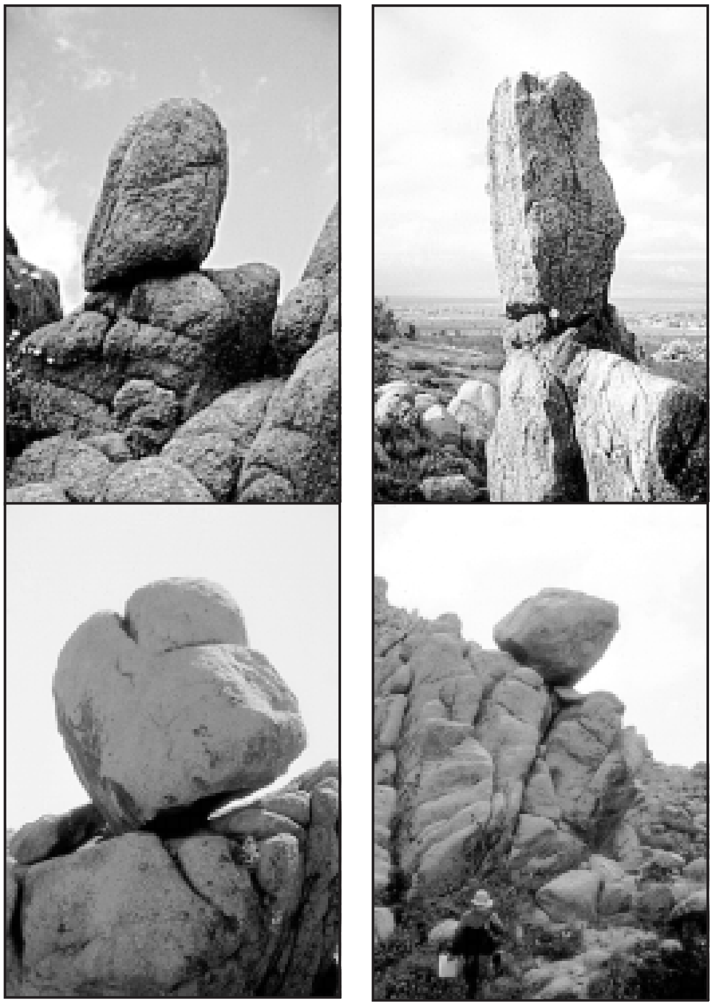
Brune's methods for studying precarious rocks use observations of rock varnish (a dark, uniform finish) to assess how long they have been in place. Rock varnish, combined with local geomorphic evidence, can help establish the approximate length of time precarious rocks have been in their present positions. For example, in a study he conducted in the vicinity of known historic earthquakes in northern Nevada, no delicately balanced rocks were found. Rock "aprons" on steep sidehills "showed instability, including mixtures of rocks with fresh surfaces that lack desert varnish, rocks that have been flipped over with dark varnish on the bottom and red oxide (typical of the underside of rocks) on the top, and abundant rocks with multiple impact marks."

Ground accelerations necessary to topple some precarious rocks can be estimated with stability calculations, force tests in the field, and artificially induced ground motion. In addition, studies of areas of recent high ground motion further calibrate the methods (Brune, 1992). A statistical study of a number of rocks is

About the researcher: James N. Brune is director of the Seismological Laboratory at the Mackay School of Mines and professor of geophysics in the Department of Geological Sciences at the University of Nevada, Reno, a SCEC core institution. Brune is the recipient of numerous honors and awards, including the 1997 Seismological Society of America Medal, an award given for scientific contributions that bolster the overall field of earthquake science and engineering.

When presenting the medal to Brune, Ralph Archuleta, president of SSA, pointed out that Jim's mentors, colleagues, and students have "universally commented on his deep intuitive approach to addressing fundamental problems. Phrases such as 'extraordinary intuitive sense,' 'incredible strength of intuition and sharpness of reasoning,' and 'remarkable physical insight' are used to describe his approach to science."

Brune and his colleagues recently submitted two papers to *Seismological Research Letters*: "Precarious Rocks Along the Mojave Section of the San Andreas Fault, California: Constraints on Ground Motion from Great Earthquakes," and "Probabilistic Seismic Hazard Analysis without the Ergodic Assumption" (with John Anderson). For this article, we've abstracted from the first paper (with Brune's permission), including a few photos and figures provided by Brune, to help our readers appreciate one of the more innovative approaches to seismic hazard analysis.



Photographs of the types of rocks that are being studied as precarious or semi-precarious. (Photos by James N. Brune)

necessary to eliminate the influence of accidental occurrences. More recently, Brune and his colleagues have concentrated on the quantitative aspects of understanding precarious rocks through comparative studies of numerical modeling and physical experiments (Baoping Shi et al., 1993).

The term "precarious rocks" needs no explanation when linked to photographs like that on the cover of this issue. Some of these rocks have been in place for thousands of years and have remained intact through numerous historic and geologically recent earthquakes. According to Brune, groups of precariously balanced rocks are effectively strong ground motion "seismoscopes" that have been operating on solid rock outcrops for thousands of years, thus providing a limit on the maximum ground motion that could have occurred during that time.

In a 1996 study, he and his colleagues found that the distribution of precarious rocks in southern California was not consistent with the large values of ground motion predicted by Probabilistic Seismic Hazard Analysis (PSHA) studies. He found, with the exception of Wesnousky's 1986 PSHA map, all PSHA maps predicted ground motions larger than those based on analyses of precarious rocks. The main difference between the PSHA maps and Wesnousky's map is that Wesnousky used only the mean value for attenuation of peak ground acceleration with distance, whereas the PSHA maps added a statistical (Gaussian) uncertainty to the ground motion for each magnitude and distance (Stirling et al., 1997).

For his SCEC project, Brune and his colleagues focused on rocks near the Mojave section of the San Andreas fault in the Mojave near Palmdale and in the adjacent San Gabriel Mountains. In these areas, numerous balanced rocks, estimated to be precarious and semi-precarious, were found at distances between 11 and 35 km from the fault.

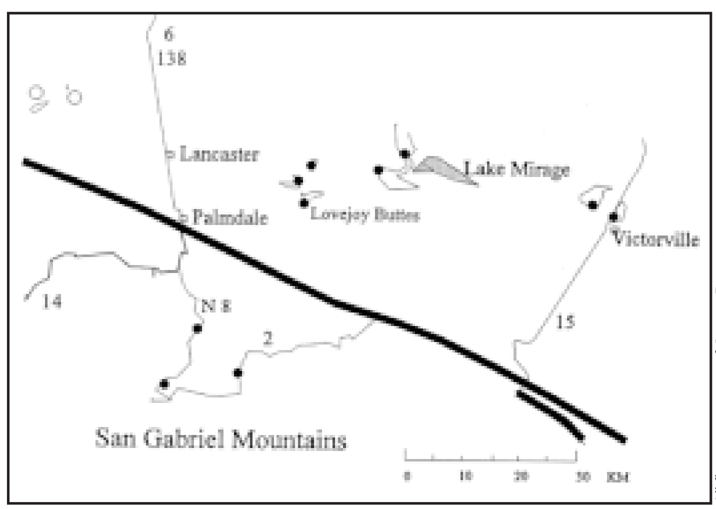
A considerable number occur at Lovejoy Buttes, 14 to 17 km from the San Andreas. An accompanying figure gives the locations of these rocks. At the closer distances (Lovejoy Buttes and Alpine Buttes) the rocks are less precarious ("semi-precarious"—see Brune, 1996), and there are also numerous examples of rocks that appear to have been shaken down. At larger distances there are numerous precarious rocks still standing and fewer examples of rocks that appear to have been dislodged.

Brune sees a clear transition between precarious and semi-precarious rocks as the distance increases from the San Andreas fault. The same general conclusion, says Brune, applies for the distribution of precarious and semi-precarious rocks to the southwest in the San Gabriel Mountains.

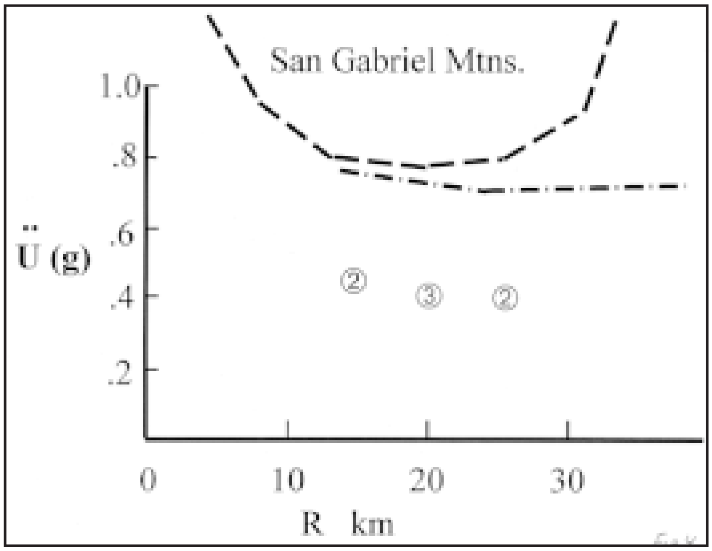
The PSHA maps for the San Gabriel Mountains southwest of the San Andreas are controlled by ground motions from the San Andreas and the Sierra Madre frontal thrust along the southern flank of the San Gabriels (northeast edge of the greater Los Angeles basin). As a consequence, the PSHA values for the Frankel et al. (1996) and Ward (1996) maps decrease to the south of the San Andreas for distances of only 10 km, then flatten, and increase as the effect of the Sierra Madre fault, dipping northeast under the mountains, begins to be felt (see accompanying figure).

There are three zones of semi-precarious rocks in the San Gabriel Mountains that give

Map showing the locations of precarious rocks in James Brune's study.

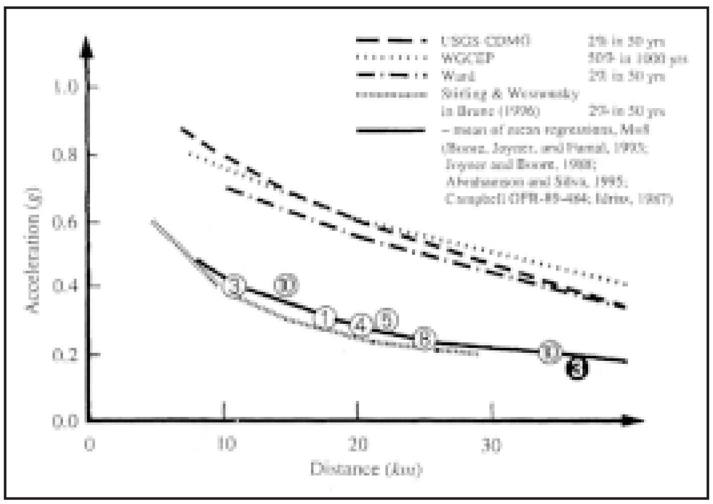


All figures courtesy of James Brune



Above: Comparison of estimates of toppling accelerations of precarious rocks in the Mojave Desert with PSHA estimates (from published PSHA maps) and with approximate mean of mean attenuation curves derived by various authors. Numbers in the circles are the number of rocks found to give reliable estimates of toppling acceleration.

Below: Same information for the San Gabriel Mountains.



preliminary estimates of toppling accelerations. Brune's conclusion is similar to that for the Mojave Desert data: disagreement with the "2% in 50 yr" maps.

His preliminary results from the San Gabriel Mountains support the conclusion that the Frankel and Ward mapped accelerations are too high. Further study of the precarious rocks in the San Gabriel Mountains, says Brune, may provide important limits on ground motion from the frontal thrust, and also provide important limits on ground motion input for calculations of the seismic response of the Los Angeles basin.

Related Research

Anderson, J. G., and J. N. Brune (1998a). Methodology for using precarious rocks in Nevada to test seismic hazard models, submitted for publication.

Anderson, J. G., and J. N. Brune (1998b), Non-ergodic probabilistic seismic hazard analysis, annual meeting of the Seismological Society of America, Boulder, CO, abstract.

Bell, John W., J. N. Brune, Tanzhuo Liu, Marek Zreda, and James C. Yount (1998). Dating precariously balanced rocks in seismically active parts of California and Nevada, *Geology* in press.

Bolt, B. A. (1993). *Earthquakes*, New York: W.H. Freeman and Company.

Brune, J. N., J. W. Bell, and A. Anooshehpoor (1996), Precariously balanced rocks and seismic risk, *Endeavor*, New Series 20, No. 4, 1996.

Brune, J. N. (1996), Precariously balanced rocks and ground motion maps for southern California, *Bull. Seism.. Soc. Amer.,* 86:43–54.

Frankel, A., C. Mueller, T. Barnhard, D. Perkins, E. V. Leyendecker, N. Dickman, S. Hanson, M. Hopper (1996). National Seismic Hazard Maps, June 1996, U.S. Department of the Interior, U.S. Geological Survey, MS 966, Box 25046, Denver Federal Center, Denver, CO 80225.

Shi, B., A. Anooshehpoor, Y. Zeng, and J. N. Brune (1996), Rocking and overturning of precariously balanced rocks by earthquake, *Bull. Seism.. Soc. Amer.*, 86:1364–1371.

Stirling, M. W., A. Anooshehpoor, J. N. Brune, and S. G. Wesnousky (1998), Assessment of site conditions of precariously balanced rocks in southern California, *Bull. Seism. Soc. Am.*, submitted.

Ward, S. N. (1995), A multi-disciplinary approach to seismic hazard in southern California, *Bull. Seism. Soc. Am.*, 85:1293–1309.

Weichert, D. (1994). Omak Rock and the 1872 Pacific Northwest earthquake, *Bull. Seism. Soc. Am.*, 84:2:444–450.

Wesnousky, S. G. (1986), Earthquakes, Quaternary faults, and seismic hazard in California, *J. Geophys. Res.*, 91:12587–12631.

Wesnousky, S. G. (1994), The Gutenberg-Richter or Characteristic earthquake distribution—which is it?, *Bull. Seism. Soc. Am.*, 84:1940–1959.

Working Group on California Earthquake Probabilities (1995), Seismic hazard in southern California: probable earthquakes, *Bull. Seism. Soc. Am.*, 85:1994–2024.

SCEC Workshop on Physics, Future

The Southern California Earthquake Center is hosting a workshop on the physics governing the behavior of earthquakes and faults. The workshop will be in Utah from June 21 through June 23, 1998. The objective is to assess the current state of understanding of the earthquake process. There are many approaches to such problems including continuum mechanics, statistical physics, laboratory experiments, and field observation. By bringing together experts in these various approaches, we hope to compare results and identify key problems for future research.

This workshop is timely as the staff works toward renewing SCEC as the new California Earthquake Research Center. A primary objective of the workshop will be to produce a list of key problems and proposed methods of approach that can be incorporated into the renewal proposal and guide the center's strategic plan for earthquake physics research. A second objective will be to identify important directions and modes of interaction between the various SCEC / CERC groups.

New Web Address for USGS Seismic Bulletins

The web address for the Southern California Seismic Network Bulletins under the USGS Web Sites heading has changed slightly. It is now: HTTP: / / WWW-SOCAL.WR.USGS.GOV / LISA / NETBULLS.

Interview with SCEC scientist . . .

Jean-Bernard Minster

SCEC Quarterly Newsletter includes interviews with SCEC scientists to highlight the interviewees' research projects and interests. We also discuss other projects and subjects to give a view of the scientist as participant in the larger scientific community and society in general. In this issue, SQN interviews the vice-chair of SCEC's board of directors and eminent geophysicist Bernard Minster.

SQN—Will you describe your educational background in France?

JBM—In the French system, the best high school students have the option to take an extension of high school for two or three years called "preparatory classes." During that time, they take intensive math, physics, and chemistry, languages, and other things to prepare for a nationwide competitive examination for engineering schools. At the end of the second or third year, they take the exam for admission to engineering schools. It's very different from the standard university path. It's very competitive.

Out of 2,000 applicants, I was one of 60 accepted to the School of Mines of Paris. It, together with the Ecole Polytechnique and the Ecole Normale Superieure, is one of the top engineering schools in the country. They are also located in Paris.

SQN—What first interested you in earth science?

JBM—I had a basic education in math and physics. At the School of Mines, I was exposed to geology, which I loved. However, trying to reconcile my interests in math, physics, and geology led me to geophysics.

I graduated in 1969 from the School of Mines of Paris with a degree in mining engineering and simultaneously from the French Petroleum Institute, which I also attended in my last year, with a degree in petroleum engineering.

SQN—Why did you come to the U.S?

JBM—Though my professors in France tried to discourage me at the time, I felt ready to "see the world" and applied to graduate school in the U.S. I was turned down by Pittsburgh and Salt Lake City but accepted by Caltech. At Caltech I was introduced to seismology by my advisor, Prof. Charles Archambeau.

As far as I am concerned, I was extremely lucky, not only to have the kinds of professors and mentors that the Caltech Seismological Lab has to offer, but also the exceptional fellow graduate students at the lab who taught me how to do research in cooperation with others. These are friends I will keep for life.

I graduated in 1974 and had to return to France to meet my military obligations. I served in the French Air Force, detached to the French Atomic Energy Commission.

SQN—Is that where you started your work with nuclear test monitoring?

JBM—No, I started that during my Ph.D. work. Some of the applications of my Ph.D. research had to do with nuclear monitoring. At that time I was already involved in joint research with Systems, Science and Software (S-Cubed), the company I joined in 1980. We did a lot of numerical modeling of earthquake and explosion sources.

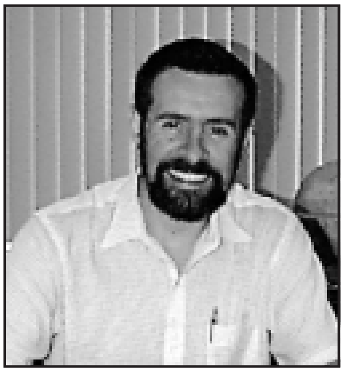
SQN—Did you return to the U.S. immediately after your military duty?

JBM—After only one year in France, I decided that my sweetheart in the U.S. was the girl to marry, and I asked her to wait an extra year for me. I came back a few days before Christmas in 1975. We were married in March 1976. I was lucky enough to get a job in the U.S. at the time.

> My experience in the private sector taught me that fundamental science and commercial interests are not altogether incompatible. It also taught me something about myself: even though I can work well in a commercial environment, I missed the interaction with graduate students, the intellectual challenge.

SQN—Where did you work after returning?

JBM—I was an assistant professor and then an associate professor at Caltech. In November 1980, I had an opportunity to join S-Cubed in San Diego as Program Manager for Theoretical Geophysics.



Bernard Minster

SQN—Why did that draw you away from Caltech?

JBM—I had always wondered whether I was the kind of person who could make it in the private sector. I decided that that was the time to try it rather than waiting until I retired. Besides, the idea of living near the beach in San Diego held considerable attraction!

SQN—Did you make it in the private sector?

JBM—I did pretty well. However, after three years, the company went heavily into the "Star Wars" type of research. I thought that geophysics and earthquakes had little to do with that, so a couple of partners and I left the company and formed Science Horizons, Inc.

We worked for four years together to develop a variety of things, but mostly database and data analysis systems for treaty verification. Our main business was twofold: (1) to develop seismic data analysis systems on workstations (SUN workstations were then emerging as major players on the market) and (2) to develop real-time digital data transmission and acquisition systems for seismic stations and arrays (such as ARCESS in northern Scandinavia).

Our customers were primarily DARPA and the U.S. Air Force, but we also had a few commercial customers—in spite of the severe cutbacks in the oil industry at that time.

We were using some of the first UNIX workstations. S-Cubed bought one of the first models ever built by Sun Microsystems. It had serial number 99. We got to demonstrate its use at the United Nations in Geneva. It was really exciting. It was a highlight of my life in the private sector.

SQN—Why did you leave the private sector?

JBM—In 1987 I left Science Horizons mostly because I missed the interaction with students. The company has since continued to flourish and diversify.

My experience in the private sector has been a very good one. It has taught me that fundamental science and commercial interests are not altogether incompatible. It also taught me something about myself: even though I can work well in a commercial environment and although I can appreciate the drive surrounding a for-profit research endeavor, at the end of the day, I prefer to work with students in an academic environment. I missed the interaction with graduate students, the intellectual challenge.

I was lucky that a visiting professorship opened at the Institute of Geophysics and Planetary Physics (IGPP). I applied and was accepted, so I didn't even have to move. I was a visiting professor from 1987-89. In 1989, I applied for and received a permanent faculty position with the University of California at Scripps Institution of Oceanography (SIO).

SQN—Why Scripps? What are your interests there?

JBM—I am extremely interested in the University of California as a fundamental component of higher education in the state of California and as the producer of a large work force with an advanced education.

I feel very fortunate to be a member of SIO, the leading institution of this kind in the U.S.—and the world. I feel a profound allegiance to IGPP, a multi-campus research unit of the University of California. It embodies excellence in research in all disciplines of the geosciences, from the study of ancient life to the study of black holes, to archeology, seismology, mantle convection, ocean and atmospheres of various planets, magnetospheres of planets and stars, and any number of intermediate disciplines.

> I think it's fair to say that nuclear treaty verification has been a tremendous boon to seismology since the early 1960s in both fundamental research and the development of technology.

SQN—Do you still have a connection with the French space program?

JBM—We have just submitted a "step 1" proposal to the NASA Earth System Science Pathfinder (ESSP) program of small low-Earth orbit observation satellites. The blockbuster technique of the 1990s is Synthetic Aperture Radar Interferometry. Our proposal is for the Earth Change and Hazard Observatory Synthetic Aperture Radar satellite.

It is proposed as a bilateral U.S.-French instrument operating at both L and C band (hence the name ECHO-Elsie), dedicated to the study of (1) the earthquake cycle, (2) the volcanic cycle, and (3) the cryosphere. Of course it will be able to do a lot more. Our intent is to build on the phenomenally successful European ERS 1 and 2,

Professional Highlights
BERNARD MINSTER

Education
B.S., Mathématiques—Académie de Grenoble
Graduate, Ingénieur Civil—École des Mines de Paris
Graduate, Ingénieur du Pétrole—Institut Français du Pétrole
Ph.D., Geophysics—California Institute of Technology
Doctorat d'État, Géophysique —Université de Paris VII

Professional
Systemwide Director, Institute of Geophysics and Planetary Physics
Professor, Scripps Institution of Oceanography, UCSD
Associate Professor, California Institute of Technology

Honors
Nordberg Lecturer, Goddard Space Flight Center
Fellow, American Geophysical Union
Cecil and Ida Green Scholar, IGPP

Recent Research Subjects
- Determining the structure of the Earth's interior from broadband seismic data; imaging the Earth's mantle and crust using seismic waves.
- Use of seismic means for verification of nuclear test ban treaties.
- Application of space-geodetic techniques to study tectonic and volcanic deformations of the Earth's crust.
- Ionospheric disturbances caused by earthquakes, rockets, mining blasts, and other explosions, using GPS.
- Validation of earthquake prediction methods based on pattern recognition techniques.

Recent Publications
Ridgway, J. R., J. B. Minster, N. Williams, J. L. Bufton, and W. B. Krabill, Airborne laser altimeter survey of Long Valley, California, Geophys. J. Int., 131, 267-280, 1997

Hofton, M. A., J. B. Blair, J. B. Minster, J. R. Ridgway, N. P. Williams, J. L. Bufton, and D. L. Rabine, Using laser altimetry to detect topographic change at Long Valley caldera, California, Earth Surface Remote Sensing, SPIE, 3222, 295-306, 1997.

Shkoller, S. and J. B. Minster, Reduction of Dietrich-Ruina attractors to unimodal maps, Nonlinear Processes in Geophysics, 4, 63-69, 1997.

Calais, E., J. B. Minster, M. A. Hofton and M. A. H. Hedlin, Ionospheric signature of surface mine blasts from Global Positioning System measurements, Geophys. J. Int., 132, 191-202, 1998.

Xu, H., S. M. Day and J. B. Minster, Model for nonlinear wave propagation derived from rock hysteresis measurements, J. Geophys. Res., submitted, 1998.

Japanese JERS, and Canadian RadarSat missions, with a mission dedicated to science applications.

When we proposed this before, we received a very good science review, but we were over the budget guidelines. This time, we are proposing it as a bilateral mission with the French Centre National d'Etudes Spatiales (CNES). The idea is to put together something patterned after TOPEX/Poseidon, an oceanographic altimetry mission that has been extremely successful. We're proposing to do something similar for land surfaces using Synthetic Aperture Radar.

According to the rules of the ESSP program, I would be the PI, with deputy PIs Howard Zebker at Stanford, Paul Rosen at JPL, and Didier Massonnet at CNES. The cost to the U.S. would be under $120 million, which is far lower than any of the other missions I mentioned (each one cost well over half a billion dollars). It would be less than the movie *Godzilla* cost! And it would be dedicated to science.

Our French partners are very generously offering a launch on an Ariane 5 booster. ECHO-Elsie would be a piggyback mission on another French mission, so we can take advantage of the enormous lift capacity of the Ariane 5. The French would provide the launch and the technology for a very precise orbit determination and control. The U.S. would provide the satellite and the radar system. We would share the ground system and the data management and distribution system. It's a very good arrangement.

SCEC has been an incredibly successful endeavor. A lot more successful than I as an individual had expected in the early years. I think that we, collectively, should be very proud of what we have wrought.

SQN—Can you briefly explain the relationship among the UCSD, Scripps, and IGPP?

JBM—To an outsider, it must seem incredibly complicated. The university has nine campuses. UCSD is one of those campuses. UCSD is divided into three major units—the Main Campus, the School of Medicine, and the Scripps Institution of Oceanography. The graduate department of Scripps is an academic department of UCSD. This is where my professorship is held.

UC also has what are called Multi-Campus Research Units (MRUs) organized research units that cover more than one campus. IGPP is one of those. IGPP has branches at UCLA, UCR, UCSD, and at Los Alamos National Laboratory and Livermore National Laboratory, which are managed by UC. Those five branches make up IGPP. Each branch has a branch director. I am the systemwide director of IGPP.

It becomes a little more complicated at the level of the UCSD campus. The IGPP branch at UCSD overlaps with Scripps. John Orcutt, the branch director of IGPP is responsible to the director of the Scripps Institution. In my position at UCSD, I am responsible to the branch director. But when it comes to multi-campus research authority, he's responsible to me. That's what makes it complicated.

SQN—You are described as a "founding father" of SCEC. Can you describe the early planning, the issues you faced, the discussions, the policies decided on back in the late 1980s?

JBM—SCEC was created at a time when "the idea was ripe and timely," as is the idea of a statewide effort now. I was not part of the earliest planning, because I was out of town—at sea, actually—at the time. The important discussions and policies had mostly to do with the collection, management and distribution of data, and with the issues of making these data available to all and selecting research directions that would advance the science of earthquakes.

SQN—Can you describe the early work on the Master Model?

JBM—The basic idea behind the "Master Model" was Keiiti Aki's. My only contribution was to devise a graphical representation that people could relate to. This happened in the course of a two-hour discussion in Kei's office. This was one of these wonderful situations where all of a sudden everything clicks and all the concepts come together into a paradigm that all participants can understand and subscribe to.

SQN—How did your private sector experience influence your career and your outlook on earth science?

JBM—I think it gave me a broader outlook. Some people who function only within the academic environment do not necessarily have a realistic view of how the private sector works—the motivations, the procedures, and expertise available there. In my case, it was a very useful exposure to another side of the world.

SQN—To what extent were the hardware and software of treaty verification directly applicable to seismic research?

JBM—It's all very much the same. It's very scientifically based. The scientific researchers in the private sector and the scientific researchers in academia exchange views and publish papers together and do research together. Ever since the mid 1960s that's been true. In fact, I think it's fair to say that nuclear treaty verification has been a tremendous boon to seismology since the early 1960s in both fundamental research and the development of technology.

We have such an excellent team, it would be sinful for us not to come up with a very good proposal.

This is a model of how government and policy requirements can drive scientific research in a way that's extremely constructive. Specifically, we were working under the excellent guidelines developed by the Department of Defense to support and promote the interaction among basic research, technological development, and actual application.

From the time of my Ph.D. thesis work, I have had a continuing interest in treaty verification. In the 1970s I worked on source theory and on attenuation of seismic waves. In the 1980s I worked on discrimination between single explosions and so-called “ripple-fired” mine and quarry explosions. My colleagues Michael Hedlin and John Orcutt have played a very important role in this area.

More recently, I have been working with colleague Eric Calais on the excitation of acoustic and gravity waves in the ionopshere by seismic sources. It turns out that even a moderate-sized quarry blast (3 million pounds of ANFO explosive, or about 1-2 Ktons) will excite ionospheric disturbances as strong as a fairly large shallow earthquake (e.g., Northridge). This research is still very immature, but we have shown that GPS signals “see” these ionospheric waves very handily. In this respect the SCIGN network, which SCEC spearheads, will provide us with critical data sets.

SQN—Do events such as the nuclear testing recently done by India and Pakistan have an effect ultimately in seismic research?

JBM—What happened in India is very challenging. Though not a big event, it is located in an area that makes analysis very difficult because the regional earth structure is very complicated and the distribution of seismic stations is not ideal.

Yet it is an extremely important event. There’s no question about that. It gives us a wake-up call: we have to keep working on improving the technology, improving the science, improving our ability to detect, analyze, and identify such events. If we didn’t do a good job on this one, how could we do a good job on a more mysterious one?

SQN—Is India, then, a test case for international verification?

JBM—“Test case” is not the term I would use. I would say that this *calibrates* the challenge at hand in the context of a worldwide comprehensive nuclear test ban treaty.

SQN—Time is something that most SCEC researchers seem to have little of. Does that mean that more of the burden of keeping an eye on the big picture falls on you and others in administrative positions?

JBM—I think that’s a fair description of the job of anyone who accepts that some fraction of his or her time will be devoted to administrative duties. It’s very true, for instance, of both directors of SCEC.

Tom Henyey, for instance, is excellent at understanding the bits and pieces but also the bigger picture and bringing it to the rest of SCEC. Tom is a superb director of SCEC, and if we ever have a California-wide center, he would be an excellent director for that center.

Similarly, Dave Jackson, as science director of SCEC, has given us a sense of scientific direction that is essential for such a diverse center to function well. He is devoting a considerable fraction of his life to this endeavor, at substantial personal cost.

> The study of natural Earth systems is intimately involved in public policy and the economy of the world. We cannot avoid that, but we have not quite come to grips with it.

SQN—You were a founder of SCEC and are vice-chair of the board of directors. How does your IGPP work interact with your SCEC participation?

JBM—It’s all one big project. Intellectually, we want to understand earthquakes in the sense of a process; if we understand the process better, maybe some day we can detect or identify aspects that have precursory capabilities. Basically, what we want to do is to understand the physics of earthquakes.

Right now, we understand bits and pieces. As time goes by, we understand more bits and more pieces. My view is that what we want to do is understand the whole.

SQN—Will the bits and pieces become a whole?

JBM—I wouldn’t be in this business if I didn’t believe that. It’s true in all the sciences that you always work on bits and pieces. The important thing is that you devote some time to taking stock to see how the pieces fit in the bigger picture.

SQN—Speaking of a statewide center, do you think there will be one?

JBM—If the proposal looks good from a scientific point of view, it would be reasonable for the National Science Foundation to fund it. We still have to write a very good proposal. That hasn’t yet been done. All the ingredients are there, but even with all the right ingredients on the table, you still need a good chef.

SQN—Who’s going to be the chef?

JBM—I believe that we have the leadership right now, primarily Tom Henyey and Dave Jackson along with the scientific leaders in northern California. We have such an excellent team, it would be sinful for us not to come up with a very good proposal.

Now whether this proposal wins when compared with competing proposals is an unknown. There are many areas of science where we get excellent people competing. It’s OK to lose to excellent competitors. It’s not OK not to produce the best proposal we can.

SQN—Will space-based activities and research play a more prominent role in the program of the new statewide earthquake center, if it is funded?

JBM—Definitely. I think that remotely sensed data are going to be critical in the next generation of models for earthquake processes.

SQN—How do you see the future of the new center? What will it look like, what will it be doing, and what will it have accomplished in 2010?

JBM—The new center will take advantage of major new advances in observational technologies, computational capabilities, and in digital communications. The data we have painstakingly collected over all these years will be assimilated in physically based models, which will offer a mechanism for step-wise predictions of the state of the geological systems, and therefore offer a clear way to *test* the hypotheses we can

Minster on Space Geodesy

In the 1970s my best friend Tom Jordan (now a professor at MIT) and I worked on the determination of plate motions from geological data, such as ocean floor magnetic anomalies, transform fault bathymetry, and earthquake fault plane solutions. This work yielded plate kinematics models valid for the past 2-3 million years.

In the late 1970s and early 1980s, a new discipline came to the fore: space geodesy. The techniques that were developed first included Very Long Baseline Interferometry (VLBI) and Satellite Laser Ranging (SLR). When NASA started its Crustal Dynamics Project, we wrote a proposal that was accepted and we became part of this tremendously exciting revolution in geodesy. The magic of space geodesy is that you can “see” plate tectonics essentially in real time and can compare the estimates of plate motions for million-year averages and for 5-year averages.

In the late 1980s, a technique that was first proposed nearly a decade earlier by Peter McDoran and colleagues become a practical geodetic tool. GPS precise geodesy had come of age. It blossomed in the early 1990s with the advent of the Permanent GPS Geodetic Array in southern California, as well as similar dense GPS networks in Japan, as well as with the creation of the International GPS Geodetic Service (IGS) of the IAG.

I participated in these exciting endeavors with a sense of awe that has not abated and feel that they have brought to the earth sciences a remarkable injection of high-tech applications that have resulted in a thoroughly renewed outlook on earth deformation measurements at all scales. The use of continuous GPS arrays for studying earthquakes is a major SCEC activity, with strong worldwide leadership from Yehuda Bock, Bob King, Dave Jackson, Ken Hudnut, and Frank Webb, among many others.

Since 1993, I have also been involved in precise airborne and spaceborne laser altimetry. We are talking about measuring the altitude of the Earth’s surface to an accuracy of about 20 cm, over a footprint of 1 m to 70 m, by measuring the roundtrip travel time of a short pulse of light (1 nanosecond long) from an aircraft navigated by GPS, the Space Shuttle, or a free-flying spacecraft.

Precise laser altimetry is becoming a practical geodetic technique. It is much more effective than radar altimetry over land because the slopes are much steeper than over water (which really hurts radar techniques) and because the footprint is much smaller (tens of meters instead of several kilometers). With precise GPS-determined orbits, we can now conceive of repeat-pass crossover analysis that should detect slow changes in the total volume of polar ice sheets, a proxy for global climate warming. The Geoscience Laser Altimetry System, the instrument for the ICESAT mission to be launched in July 2001, will do just that among other things. I am a member of the ICESAT science team.

Airborne applications include mapping volcanic inflation. An example is Long Valley Caldera, near Mammoth Lakes, CA, where we have been flying laser altimetry missions using NASA aircraft since 1993. Airborne experiments are a crucial part of getting ready for a space mission like ICESAT.

So far, we have been able to demonstrate reliable altitude determination for well-surveyed surface features at the 2-3 cm level. For example, we can see the slope of the geoid in the surface of Lake Crowley, over distances of 1-3 km. My colleagues Jeff Ridgway, Michelle Hofton, and Nadya Williams have been instrumental in this effort, together with an entire crew of NASA Goddard Space Flight Center and NASA Wallops Flight Facility scientists and engineers.

The study of earthquakes should really involve all phases of the “earthquake cycle,” from the co-seismic, to post-seismic, to inter-seismic, to pre-seismic portions of the cycle. Different physical phenomena dominate different portions of the cycle. Seismology, per se, “sees” mostly the co-seismic phase. Geodesy and other measurements see the other portions, which are much subtler and which involve much longer time scales.

derive from what we already know.

SQN—Since you were involved with SCEC from the proposal stage to now, has SCEC fulfilled your vision of what it would and should be?

JBM—SCEC has been an incredibly successful endeavor. A lot more successful than I as an individual had expected in the early years. It has brought people together from very different disciplines to work on the same problem from different angles—to listen and to hear from people in the other disciplines. SCEC also provides the infrastructure to deliver critical education and outreach, linking the high-tech side of the science to the practical side. I think that we, collectively, should be very proud of what we have wrought.

It is, however, time for SCEC to evolve. It was logical for SCEC to start looking at probabilistic hazard assessment, but the logical evolution is toward a more profound understanding of the physics that govern probabilistic assessment. That means moving toward what we call a physical master model.

SQN—Is there any disagreement among your colleagues about the need for a physical model?

JBM—No, there is not a single argument against that. I think that everybody agrees that it would be beneficial to have a physical model. But not everybody agrees on the ingredients of a physical model.

We have ideas. Some of us have very strong ideas, but we don’t know what the model will be ultimately. I think we all agree, though, that this is the natural evolution of our notion of what a model should be to allow us to understand the earthquake phenomenon better.

SQN—What is your current workload?

JBM—Right now, I am spending a lot of time on issues of the Senate of the University of California (I chair the systemwide Committee on Planning and Budget). I also spend much time on IGPP, where I am the systemwide director. This takes about 50% of my time.

Then I am involved in developing major proposals such as ECHO-Elsie. In addition, I am a player in the "General Earthquake Model" (GEM) proposal to the NSF KDI program and a co-investigator in another KDI proposal on multisymplectic integrators to deal with nonlinear natural systems. And, of course, I am teaching and doing a bit of research (mostly through colleagues and students). This accounts for the other 100% of my time.

SQN—You seem to have a view of earth sciences in a larger context that includes politics and economics. Can you explain your view in that sense?

JBM—Earth sciences in the general sense, by which I mean the sciences that deal with Earth systems—the atmosphere, the ocean, the solid earth, perhaps also the magnetosphere and the ionosphere, interplanetary space, life on other planets, new planets in distant solar systems—all that body of science has an enormous amount of input to provide in policymaking.

This has been true ever since we started understanding that systems the size of a planet behave according to laws that give us some degree of predictability. We came to understand this after we started looking at global modifications of the planetary system—due to natural causes or possibly to anthropogenic causes. In that sense, our science has perhaps more profound implications in terms of public policy than most sciences have. It's true in terms of how we deal with societal response to natural disasters.

Look, for example, at the tremendous success of volcanology in the case of Mt. Pinatubo. Look at the tremendous impact of natural phenomena such as hurricanes Hugo and Andrew, or earthquakes at Loma Prieta, Northridge, and Kobe on the insurance industry. You can see that the study of natural Earth systems is intimately involved in public policy and the economy of the world. We cannot avoid that, but we have not quite come to grips with it.

What we need to do is to come to grips with this reality as a community—a scientific community—and identify the areas where we can have some reasonable positive impact, based on scientific discourse and scientific facts.

SQN—Are you saying that scientists need to be aware of things beyond pure science?

JBM—That's absolutely right. We need to be aware of it, and we need to be sensitive to it. This is particularly true in terms of natural disasters—hurricanes, tornadoes, etc. When it comes to earthquakes, it becomes dicier. We can and should prepare for the anticipated impact of large earthquakes. We have a very difficult time when it comes to earthquake prediction. We can't predict earthquakes—not even on the short time scales over which we can predict the impact of hurricanes.

SQN—Should earthquake prediction be one of our goals?

JBM—It should most emphatically be one of our goals. If there is a chance of success, we should pursue it vigorously.

There are many facets to this problem. For instance, we know that someday there will be a large earthquake under Tokyo. The same is true with Seattle, San Francisco, Los Angeles, Mexico City, and many other major metropolitan areas. We don't know how to say when, but we know that it will happen. In that sense, we have the responsibility to make sure that we can clearly state the consequences when large earthquakes strike.

For instance, if there were a large earthquake near Singapore, there would be major consequences—not only for Singapore, but for the worldwide economy. There would be major consequences for the enormous U.S. assets in that city. We need to be sensitive to this and not think just about seismology.

I think that this is where organizations like SCEC can help—SCEC can provide a bridge between pure seismological science and societal impact, political science, economy. These are not easy questions to answer or easy goals to achieve.

I think we should have as broad a discussion as possible. Ultimately, this debate should not be restricted to California—or even to the borders of the United States. This is a worldwide problem. Frankly, if we look at it on a worldwide basis, we will likely make progress faster and on a broader front than if we stick to a more parochial point of view.

Interviewer: Ed Hensley

The Trojan Horse Might Have Been an Earthquake

"Don't blame sneaky Greeks in a hollow horse for breaching ancient Troy's defenses. Don't look to besieging armies to explain Jericho's repeated destruction. Don't ask who buried some of the Dead Sea scrolls. Impersonal earthquakes—not human violence—may have done the job." —Robert C. Cowen, Christian Science Monitor

A recent article in *The Christian Science Monitor* discussed geophysicist Amos Nur's new look at ancient eastern Mediterranean history. Where archaeologists see mainly the remains of warfare and pillage, he sees seismic destruction.

He has also taken a new look at the region's seismicity. According to conventional theory, quakes occur independently here and there along a fault line as accumulated strain is released in local areas. Instead, Dr. Nur sees evidence that devastating quakes can occur in swarms that can unzip an entire fault line. Swarms would be separated by long periods of quiescence, lulling inhabitants into false security.

Nur, who is chair of Stanford University's geophysics department, says that such a swarm may be what ended the region's Bronze Age, when dozens of civilized centers—including Knossos, Mycenae, and Troy—were destroyed within a 50-year period.

If it happened then, it could happen now. That makes this new look at ancient history relevant to efforts to understand earthquake hazards in regions like the Middle East, where large population centers now lie along or close to dangerous fault lines.

For the full story, see the January 6, 1998, *Monitor* or the web at WWW.CSMONITOR.COM.

Featured Fault

Seismic Potential of the San Joaquin Hills

Research in Progress—An Interview with Lisa Grant

Photo: Ruth Wardwell

Lisa Grant (Chapman University) is a member of a team of researchers studying the earthquake potential of the San Joaquin Hills in Orange County. The team expects to submit its findings very soon after this newsletter goes to press. Dr. Grant's coauthors are Karl Mueller (University of Colorado), Eldon Gath (Earth Consultants International), Rosalind Munro (Leighton and Associates), Larry Edwards (University of Minnesota), Hai Cheng (University of Minnesota), and George Kennedy (San Diego State University). Though the findings are not final and therefore cannot be published yet, Dr. Grant agreed to an interview to discuss the process by which such a project begins and proceeds, as an example of SCEC-funded and SCEC-facilitated interdisciplinary research.

SQN—Would you describe the area where your team has been working?

LG—The San Joaquin Hills are located in southern Orange County at the southwestern margin of the Los Angeles basin. Some of the most scenic real estate in southern California is on the coastal side of the San Joaquin Hills near Newport Beach, Laguna Beach and Dana Point.

Geologic maps of the San Joaquin Hills show many faults. The faults that reach the surface have been examined by many geologists, and they don't appear to be active. Some of the faults have moved in the Quaternary, but apparently not in the Holocene. That's one of the reasons that the San Joaquin Hills have previously been dismissed as inactive tectonically. Our research focused not on those older surface faults, but on whether there might be one in the subsurface. Initially, we had little to go on other than a combination of intuition and circumstantial evidence. We were suspicious that something was there.

SQN—What other research has been done in that area?

LG—The main structure in the area that has been studied well is the Newport-Inglewood fault. The Holocene (active) strand is fairly close to the coast line, but there is a broader zone of older faults that extends inland through Costa Mesa and Huntington Beach. Their locations are not very well constrained. Those are mostly mapped from ground water barriers. The active trace, which has been carefully mapped through engineering geology studies and by the California Division of Mines and Geology (CDMG), goes offshore at Newport Beach, where it becomes difficult to study because it is under water.

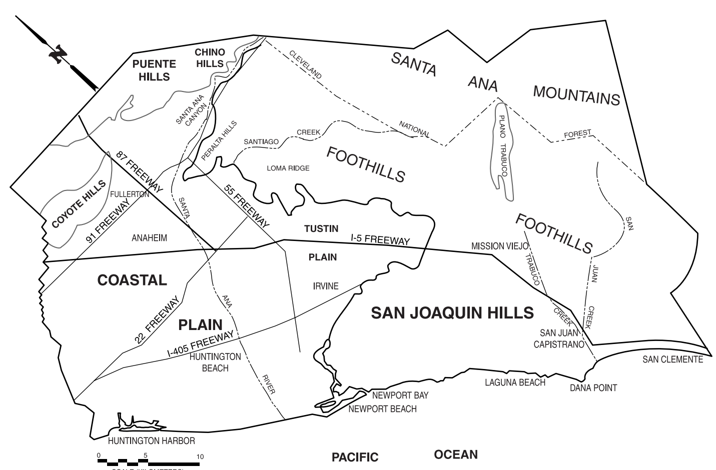
SQN—What are the features of the area that drew your team's attention to the San Joaquin Hills?

LG—There is a series of coastal mesas in the southern part of the Los Angeles basin. Beneath them is a thick sequence of sediments. The mesas have been associated with uplift along the Newport-Inglewood fault zone. Farther north in Los Angeles County, they are localized right along the Newport-Inglewood fault zone. They're clearly related to movement of the Newport-Inglewood fault.

As you get farther south, the Newport-Inglewood fault goes offshore, and the mesas get broader and higher. Then they turn into the San Joaquin Hills. That's one of the first things I noticed when I moved to Orange County in 1991. The hills were relatively undeveloped then. I could see that there was a series of what appeared to be notches cut into the hillside. They looked like marine terraces cut by waves. So it looked like the San Joaquin Hills had been rising out of the sea. I wondered whether that is true and how old those marine terraces are.

Around that time, many scientists were trying to understand the Palos Verdes fault. There is a series of marine terraces—like bathtub rings—around the Palos Verdes peninsula. By looking at those terraces, it appeared that the peninsula had been rising. The big question was why was the peninsula rising—was the Palos Verdes a thrust or a strike-slip fault?

I was at Caltech at the time. It was something we were discussing in seminars. Then I would go home to the San Joaquin Hills and think that it looked very similar. I asked, "What about the San Joaquin Hills?" No one knew. No one had looked that closely. That spurred my first interest—casually wondering whether



Map courtesy Lisa Grant

the San Joaquin Hills rose out of the sea during the Quaternary, and if so, why?

SQN—What were the first steps in finding out?

LG—My working hypothesis was that they were rising. To test that, the terraces would have to be mapped and dated to see whether they had truly risen relative to sea level.

SQN—So you suspected that something tectonic was happening instead of just changes in sea level?

LG—Yes. Sea level has gone up and down. That makes it complicated. I wanted to know if the terraces formed by changing sea level alone, or by emergence of the hills due to tectonic uplift.

In 1992 I attended an AEG (Association of Engineering Geologists) meeting that offered a field trip to Orange County. I signed up and that's where I met Rosalind Munro. She gave a presentation on the marine terraces on the coastal side of the San Joaquin Hills.

I got very excited; here was someone else who had noticed them. She'd written an abstract and pointed me to another one that had been written by several people at her company, Leighton and Associates, including Eldon Gath.

Karl Mueller was working on some structures farther north—the Compton-Los Alamitos fault. I approached him and asked him whether he'd considered looking at San Joaquin Hills. That was late 1993. By then, I was in consulting at Woodward-Clyde; I didn't think I'd pursue it as a research project. I thought that if Roz and Eldon weren't able to pursue it at the time, maybe Karl would.

Then the Northridge earthquake hit. There had been subtle evidence that the Northridge blind thrust was there. It's not so subtle now, but nobody saw it until after the earthquake.

In light of that experience and increased sensitivity to blind thrusts, I became fascinated by what I saw around my own home. I had a very personal interest in it. I knew that it would be very important to find out if a similar structure exists under Orange County.

I couldn't stop thinking about it. I saw clues everywhere. It was driving my husband nuts.

> Initially, we had little to go on other than a combination of intuition and circumstantial evidence. We were suspicious that something was there.

Every time we went somewhere, I was looking at roadcuts. He took me out to dinner for my birthday, and I just wanted to look at the exposure in the parking lot. He said, "You really have to make this a research project. Otherwise, it's going to torment you."

SQN—That sounds like the turning point. What did you do to avoid that "torment"?

LG—I started talking with Eldon and Roz. They had lots of knowledge of the area since they had done much of the grading for development.

Lisa Grant doing fieldwork in the San Joaquin Hills after the Laguna fire in October 1993. (Photo: Adrian Schneider, Woodward-Clyde Consultants)

They had an interest in the marine terraces; they had published about them. Eldon even had a license plate with a reference to marine terraces. They had been collecting data in their project files, but it wasn't collected for research. It was in consulting reports and in their personal notes.

I asked them if they were willing to point me to the right data and let me compile it. I thought we could test my hypothesis. They were very interested. At the same time, Karl was independently thinking that it was a good time to pursue the San Joaquin Hills. We all decided that if we all put our heads together, it would be a better project than any of us could do individually. And so we submitted companion proposals to SCEC in fall 1995.

SQN—After your proposals were approved, what came first?

LG—First, we compiled the geologic data about the terraces and mapped them. I worked with Eldon and Roz on the mapping. Karl compiled archival (before development) topographic maps in digital form to use as a base for our mapping. He then put our data into a database so that he could use it for structural modeling.

In some places mapping the terraces was relatively easy. They were all at the same elevation and therefore correlated very well. In other places, mapping became more complicated. It was difficult to tell which terraces correlated with which other ones.

SQN—How did you assign ages to those marine terraces?

LG—That's where the other coauthors come in. Eldon brought in George Kennedy because they had worked on the fossils in the area. Some of the marine terraces had warm-water fossils and some had colder-water fossils. In a place where we couldn't tell which terrace was which, the idea was that George could look at the fossils to help us in correlating the terraces.

That helped us correlate them, but we still couldn't assign ages to them. We mapped them, but they were just relative. We got stuck then. We had to find a way to assign some absolute ages. One way is using amino acid racemization of all these shells George was looking at. That process has been used in the San Joaquin Hills, producing general ages, but there are discrepancies and disagreements about them. The uncertainty was enough that it wasn't helping us answer the specific questions that we needed for our project.

Because he has done a great deal of this kind of dating, I asked Dan Ponti of USGS whether there is another way. He said that if we could find a coral, we would have our Rosetta Stone. We could date coral with uranium series methods. We could then tie all the amino acid data in with some well-constrained dates.

But nobody had found corals. He and his coworkers had been looking for years. That became my mission.

It was like looking for a needle in a haystack. I kept coming up empty-handed. George knew of some corals, but there was a question about whether they could be used for dating since they are part of a museum collection.

After my son was born, I had to spend more time around home and couldn't do field-work for a while, so I got on the phone and found out about a network of private collectors in the area, some of whom had published their work. I found Frank Peska, a collector who had a very nice coral from an area that we really wanted to date. He had published a paper on other aspects of the site. Kanakoff and Emerson did the benchmark scientific work on that fossil locality. After that initial work, the area was graded for development and Frank Peska collected as that work was being done.

He had documented all this. I found out about it because of his write-up for the Natural History Foundation of Orange County. He had listed a coral in one of his species lists. In fact, he could show me the collection site since it's been preserved as a greenbelt. There are still some shells in it, but it is probably going to be graded within the next year.

I asked him if he'd be willing to give it to me. He said that he'd received several requests for it before and hadn't let it out, but he decided that he would give it to me because he was also curious about how old it is.

The key to figuring this out is the multidisciplinary work. The result is much greater than the individual contributions.

Lisa Grant's daughter Erika stands at the contact between marine terrace sediments (above) and Monterey shale (below). Erika was born during the Landers aftershock sequence. (Photo: Lisa Grant)

SQN—Such dating is not an everyday lab technique. How did you get that work done?

LG—That's how Larry Edwards came in. Kerry Sieh intervened on our behalf and asked Larry if he'd be willing to do it for us. He and Hai Cheng, a post-doc working with Larry, did the dating. They used high-precision thorium methods.

Frank's coral specimen was a good large specimen and enabled us to establish absolute dates. The amazing thing is that the date came out exactly consistent with our hypothesis. That's never happened to me before.

George was able to get another coral but the date came out so far off that we could not think of any possible explanation for it. It caused a major problem. The coral was so young that it made no sense.

We were very concerned about this. It prevented us from publishing our work since we had this internal inconsistency. Hai Cheng spent a lot of time in the lab and was able to show that there was contamination of the sample. We think there was a mix-up in labeling during curation or collection of the sample.

The pieces were so small that a group of them was used for dating rather than a single specimen. Apparently, what happened was that two different kinds got into the sample. We were finally able to prove with the lab work that there was no geological significance and therefore we could throw them out.

SQN—That's quite a team effort. Did SCEC have a role other than funding?

LG—The key to figuring this out is the multidisciplinary work. I think that the result is much greater than the individual contributions. Each of us has a particular expertise or knowledge base that is complementary to the others.

Only by all working together on this were we able to accomplish what we did. SCEC facilitated that with its basic working group structure. The Earthquake Geology Working Group talked about various research problems and formulated ideas for how to pursue them. I can't think of a better infrastructure for conducting this work than what SCEC has provided.

SCEC's method of funding projects also helped. We were able to submit complementary proposals and have them considered as a package. Other funding agencies have mechanisms for doing that, but it's been easier through SCEC.

There are many ways that the SCEC structure supports this kind of work. For example, the field trip at the SCEC annual meeting was a vehicle for us to get a peer review of our work, which was very valuable.

SQN—Speaking of working together, did you ever sit in the same room as an entire team?

LG—Roz and Eldon are in consulting. Eldon is working on a Ph.D. on a different topic. Karl is in Colorado. George is in San Diego and does a lot of paleontological consulting. Larry and Hai are in Minnesota.

I have never met Larry Edwards and Hai Cheng. I don't think that the rest of us have all been in the same room at the same time. That's been one of the difficulties. Any project where you have so many people involved and all portions are very important, and the people are spread out, there can be some logistical difficulties.

> I hope that when we publish our work, it will be a reminder that southern California is seismically active and that if you're a resident, it's something you should be concerned about and you should support mitigation activities.

SQN—Can you describe the interplay between your role as scientist, teacher, mother, ordinary citizen, and your early training as an environmental engineer?

LG—Being broadly trained as an environmental geologist, I have an unusual perspective on earthquakes as an environmental problem. My primary interest is in earthquake geology. I'm fascinated by the problem of earthquakes—what causes them.

That's the basic science, but the reason I'm fascinated is that they affect me. I see earthquakes as the ultimate environmental problem. We can't control them. I'm fascinated by the science: what causes earthquakes, where are they likely to strike, how are they likely to affect us. But I also see it as an environmental problem: the interaction between people and the physical environment.

I don't know of any other earthquake scientist who was in labor during the Landers earthquake. I was vulnerable and very frightened. I missed the scientific opportunities, but I got a powerful experience of the human impact of earthquakes.

How do we respond to earthquakes, given that we can't stop them? Our response should be based on solid science.

I was at Caltech working on earthquake geology under Kerry Sieh when I got interested in the San Joaquin Hills. I wanted to know what kind of hazards might affect me, my family, my house—backyard geology, basically.

Originally, I studied environmental engineering at Caltech. I had identified a Ph.D. thesis topic on the transport of inorganic contaminants between a stream and its bed. I was working on experiments in a hydraulics laboratory, collecting data for my Ph.D. candidacy exam.

I was minoring in geology because I had long had the twin interests and because I like to see environmental problems from an earth science perspective. In my first week at graduate school, the Whittier Narrows earthquake hit. I was seduced by the earthquake science that was going on. I took a class from Kerry Sieh, and I was hooked.

How many people had died from contaminated water in California compared with the potential for all-out catastrophe from an earthquake? It seemed a more important problem to work on.

SQN—Does your background give more of a hazard focus than other earth scientists?

LG—I'm not sure that's the case. My motivation, my interest is hazard-oriented, but I think most of what I've done is pure science. I think the hazard drives my interest in the science. Most of my time I spend teaching. If I had more time for research, I might work more directly with hazard-oriented work than just pure science.

SQN—Are there knowledge transfer implications of the technical work your group is doing on the San Joaquin Hills?

LG—I think that the thorium dating will be helpful in evaluating other structures in the L.A. basin. Whenever you're dealing with Quaternary structures, dating is very important. One of the ways it's been done is to date fossils using amino acid methods, which are very good but not as precise. There haven't been very many corals available to calibrate the amino acid dates in the fossil assemblages. I've been talking with Dan Ponti, who has done a lot of this kind of work, to help find some calibration that will allow more precision in estimates of uplift rates and deformation rates farther north in the L.A. basin.

> I can't think of a better infrastructure for conducting this work than what SCEC provides.

That's a side story to what we were doing in the San Joaquin Hills, but I think that's going to be of value to other researchers.

All the authors on this current work have other interests in this project. I suspect that once we publish our combined work, there will be a sequence of papers building on different aspects of it. For example, Karl is doing a very detailed structural analysis of the area.

For now, we want to put together all the pieces of the puzzle and show that bigger picture to the world. We'll build on that later.

SQN—Do you think publishing this work will lead to opportunities for public awareness and education?

LG—I would be pleased if that's an outcome. It would be nice if I could work with SCEC's Outreach Program to make that happen. I see it as a public education opportunity. I think that's partly just my perspective as a professor.

Here in Orange County, the prevailing attitude is that we don't have damaging earthquakes. The last significant earthquake here was on the Newport-Inglewood fault in 1933. To most, it's ancient history. I hope that when we publish our work, it will be a reminder that southern California is seismically active and that if you're a resident, it's something you should be concerned about and you should support mitigation activities.

The research we do is ultimately funded by taxpayers. If they're not aware of the problem and supportive of our work, we won't have the funding for the long term. So the education aspect is very important. That's why I am happy to do this interview.

Interviewer: Ed Hensley

SCEC News Briefs • SCEC News Briefs

Plans to Make a Lasting Impact

ANNA-SCEC Partnership Concludes

Over the past year, the Los Angeles area Adams-Normandie Neighborhood Association (ANNA) has partnered with the Southern California Earthquake Center to elevate earthquake awareness and preparedness on a communitywide scale. The partners developed a model program for seismic safety to create a culture of sustainable, uniform community preparedness for a damaging urban earthquake. The partners believe the model can be cost-effectively replicated in vulnerable neighborhoods anywhere.

Last year, ANNA president Marianne Mullerleille, a resident of the Adams-Normandie neighborhood, submitted a proposal to the University of Southern California's Neighborhood Outreach Program. The Outreach Program is a nonprofit corporation with a mission to enhance the quality of life in the neighborhoods surrounding USC's University Park and Health Sciences campuses. It was created in 1993 to provide financial support to USC-community partnership projects and programs that make a visible, positive impact in our neighborhoods. Donations from university faculty and staff through the USC Good Neighbors Campaign are the sole source of USC Neighborhood Outreach funding.

The ANNA-SCEC Project partners identified several objectives addressing the overall education and safety of the community it reaches out to. Through the ANNA after-school program, the project emphasized the improvement of the quality of K-12 education and the quality of life for children who attend neighborhood schools. The program included a community initiative to improve public safety through natural disaster education and mitigation strategy planning aids reduction of crime and violence. SCEC assisted with projects to improve the neighborhood's economic development by helping families build preparedness kits, retrofit their homes, and offering low-cost gas shut-off valves from the Gas Company.

Earthquake Fair

The successful partnership culminated with the ANNA-SCEC Earthquake Preparedness Fair on Saturday, April 18. The fair was billed as a "one-stop learning and shopping center" featuring vendors who displayed their products. The locally famous "Quake Cottage" gave community members a chance to safely experience a simulated magnitude 8 earthquake. Food was provided by McDonalds and by a neighborhood chef who put his barbecuing skills to the test—explaining that this is the ideal way to cook after an earthquake. Fun and games were provided for the kids (young and old)—there were clowns, balloon animals, a moonbounce, and even the "Earthquake Game" at the SCEC exhibit.

ANNA President Marianne Mullerleille was a popular figure, especially during the raffles.

USC's School of Letters and Department of Psychology provided expertise for the required "objective evaluation." Dr. Margaret Gatz, professor and practicing clinical psychologist, has completed extensive research in the field of earthquake preparation. In her work, she examines multi-generational predictors of earthquake impact and preparedness. At the beginning of the yearlong program, Dr. Gatz, with the assistance of graduate student Kecia Watari, assessed the community's attitudes toward earthquakes

The ANNA-SCEC Earthquake Fair emphasized a combination of fun and education. Outreach Director Jill Andrews played the Earthquake Game with neighborhood kids. Others took advantage of the face painting and balloon hats.

ANNA photos by Jill Andrews & Sara Tekula

SCEC News Briefs • SCEC News Briefs

and measured its reliance on preparedness and mitigation strategies. Those who completed the surveys were given a complementary one-day earthquake preparedness kit.

Results of the study were compiled for future comparison to a post-test, and were reported at an ANNA monthly meeting. A post-test conducted at the completion of the partnership (immediately after the fair), measured the same factors in the community. The results are being compiled and will be compared to the pre-test. The partnership sparked interest in future community projects that may examine social applications of earthquake-related research. Finally, a community guidebook is under construction by SCEC. The book will be mounted on the World Wide Web as a guide to other communities. Watch for an announcement about December in SCEC publications list and web site: www.scec.org.

Outreach Specialist Sara Tekula welcomes Michael Essing (L) and Rick Smalling, of Safe-T-Proof Disaster Preparedness Company. Their "Quake Cottage" simulates an M 8 earthquake.

SCEC Presence at TechEd 98

On May 4, 1998, SCEC representatives presented Web-based instructional modules to a convention of community college educators. The event was the Community College Foundation's Technology in Education Conference in Santa Clara, California.

Outreach Specialist Sara Tekula, SCEC Data Center Manager Katrin Hafner (Caltech), and SCEC Web author / developer John Marquis (Caltech) presented the SCEC education module "Investigating Earthquakes through Regional Seismicity."

In the one-hour presentation, Tekula gave an overview of the SCEC Outreach program. Hafner and Marquis then walked attendees through portions of the module, allowing time for questions during the demonstration and at the end of the workshop.

Hafner, who also teaches at two Los Angeles area community colleges, felt that the module received "positive feedback on its usability in the community college setting." Hafner is the manager of SCEC's Data Center at Caltech. The module uses the Data Center's real-time data to create a dynamic learning experience, thus also advertising the many types of data presentations available on the Data Center's Web pages (www.scecdc.scec.org). Hafner noticed that "people are really excited about real-time data and how it can tie into education."

The SCEC Outreach Program has formally named its Web-based education project

DESC Online

Development of Earth Science Curricula Online

SCEC Shares Its Experience at PEER Education Program Meeting

On May 1, 1998, Pacific Earthquake Engineering Research (PEER) hosted a meeting on its Education Program. SCEC's Outreach Team reported on its education program and activities, especially changes that have taken place at SCEC in the past few months.

Outreach Director Jill Andrews outlined the current education projects, emphasizing the web-based education modules now under development. Outreach Specialist Mark Benthien spoke about SCEC's internship program for undergraduates, and Outreach Specialist Sara Tekula reported on the IRIS Education and Outreach Planning Meeting (see story in this issue).

The Education Program is directed by Gerry Pardoen (UC Irvine) and coordinated by Carrie Lincourt (UC Irvine). The education subcommittees are chaired by Scott Ashford (K-12), Abe Lynn (Undergraduate Interns), Jon Stewart (Undergraduate Scholars), Ronnie Borja (Graduate Fellowships), Kurt McMullin (Continuing Education), Gerry Pardoen (Minority / Outreach Programs), and Dave McClean (Affiliates Scholarships and Fellowships).

Scott Ashford, with SCEC's former director of education Curt Abdouch as a consultant, addressed how new Education Program could meet the needs of the K-12 community. Scott and Curt discussed internships for high school students, development of hands-on activities for teachers, links to the Future Scientists and Engineers of America (FSEA), and a partnership with the Irvine Unified School District (using UC Irvine as a gateway).

Other topics addressed included PEER's successful Undergraduate Internship Program and a commitment to conduct workshops to educate those in business and industry.

PEER brings together the premier earthquake engineering research universities in the western U.S. to develop technologies and implementation strategies to reduce the life-safety and economic risks of major earthquakes. Center researchers have expertise in diverse areas including earthquake hazards, analysis, design, risk and reliability, and economics and policy planning.

The objectives of PEER's educational program are to raise the awareness of the effects of earthquakes in urban regions and to stimulate interest in earthquake engineering among students, with a special emphasis on underrepresented minorities.

PEER programs include a public education program for teachers and students as well as the general public; an undergraduate summer intern program to attract and retain earthquake engineering undergraduates; the Earthquake Engineering Undergraduate Scholars Course; Earthquake Engineering Graduate Fellowship Program to recruit and support excellent Ph.D. students; and continuing professional education courses.

For more information about the PEER Education Program, email Carrie Lincourt at clincour@e4e.oac.uci.edu, or visit the PEER web site: http://peer.berkeley.edu/.

SCEC News Briefs • SCEC News Briefs

SCEC Represented at National Science Teachers Association Convention

Las Vegas, a city well known for lively entertainment, became a city filled with lively science teachers between April 16 and 19. The Las Vegas Hilton and the Las Vegas Convention Center served as headquarters for the 46th Annual National Conference of the National Science Teachers Association.

SCEC Outreach Education Specialist Sara Tekula joined thousands of educators at the convention, where seminars, workshops, and exhibits helped bring attendees up to date on course content, teaching techniques, and new technology applications. A primary function is simply to give them a chance to network with others who focus on the same area of interest.

According to Sara, the convention was a "great chance for teachers from all over the country to share ideas and experiences within their domains of expertise." She spoke with many earth science teachers about the integration of earthquake science into curricula and heard suggestions on how to make the SCEC web-based science education modules (currently under development) more user-friendly. Sara attended two Earth Science Share-A-Thons, where teachers demonstrated successful methods to actively engage science students through hands-on activities.

Photo: Sara Tekula

Pictured here are teachers during an earth science workshop at the NSTA Convention. In this session, the teachers were able literally to play with (i.e., learn about) dirt.

Seismic Hazard Evaluation and Mitigation Short Course

A short course for geotechnical professionals on evaluation and mitigation of seismic hazards associated with slope instability and soil liquefaction was held in Los Angeles in January. The California Division of Mines and Geology, in partnership with SCEC and UC Berkeley's Department of Civil and Environmental Engineering, sponsored the event.

The course was limited to local government reviewers of the seismic hazard reports mandated by the Seismic Hazards Mapping Act. Dr. Ray Seed, course organizer and head of the Civil and Environmental Engineering Group at UC Berkeley, said the course was "designed to present a concise but practical discussion of alternative approaches and controversial topics related to hazard evaluation and mitigation."

On the first day, speakers covered the selection and use of strong motion data, including an overview of the Statewide Probabilistic Ground Motion maps, along with seismic/dynamic soil properties and their evaluation. The second and third days were devoted to the evaluation and mitigation of soil liquefaction hazard and seismic slope instability and deformation, respectively.

More such courses for consultants and geotechnical practitioners are planned. To find out more about them, contact the UC Berkeley Geotechnical Engineering Program at (510) 642-1262.

SCEC-USGS Workshop on LARSE II

On April 21 a science seminar, sponsored by SCEC and the USGS, was held at UCLA. The goals of the meeting were to review the current state of knowledge on the deep structure of the Los Angeles Region, determine how previous phases of LARSE (Los Angeles Region Seismic Experiment) have contributed to this knowledge, and identify how the next phases will contribute more data for study.

Over 60 scientists attended the meeting organized by Paul Davis (UCLA), Gary Fuis (USGS), and Rob Clayton (Caltech). A total of 18 presentations were given. The morning focused on the Santa Monica area, which received higher than expected damage during the Northridge earthquake (1994) compared to other areas at the same distance from the epicenter. Several overview presentations were given as an introduction to the area, including evolution at the edge of the Transverse Range rotation, and more recent seismicity and structure along the Santa Monica fault.

Several theories were then presented as to the cause of the damage, including a possible deep structure related to the southern Santa Monica fault, which acted as a "lens" to focus seismic energy in the damaged region. Other studies were presented that argued that the strong shaking could have resulted by focusing much nearer to the surface related to the northern Santa Monica fault.

The LARSE II experiment is designed to resolve the controversy. It is expected that results of the Santa Monica study will be applicable to other areas where seismic energy can be focused to cause unusual damage.

The afternoon was devoted to the broader goals of LARSE II. As in the morning session, several overview presentations were given detailing the evolution, structure, and seismicity of the area to be studied. Results from Northridge earthquake studies and LARSE I were presented to show what is already known.

Also Of Interest . . .

IRIS News

IRIS Plans New E&O Program

About two years ago, the Incorporated Research Institutions for Seismology (IRIS) Consortium created its Education and Outreach Program, aiming at improving seismology and related earth science education in K-12 schools, colleges, universities, and adult education. IRIS's E&O Program has the potential to reach the entire nation through its 91 member institutions.

To create a framework for the program, IRIS formed the Education and Outreach Committee and named Catherine Johnson (formerly of Scripps Oceanographic Institute) E&O program manager. Members of the committee include Karen Fischer (Brown), Glenn Kroeger (Trinity University), Guust Nolet (Princeton), Michelle Hall-Wallace (Arizona), Jeff Barker (SUNY Binghamton), Bob Hutt (USGS-ASL), and Larry Braile, Chair (Purdue). These and other experts in education attended the IRIS E&O planning workshop in April in Warrenton, VA.

The workshop opened with a presentation on the background of the IRIS E&O Program, and selected attendees gave brief presentations on their education programs at their organizations and institutions. SCEC Outreach Education Specialist Sara Tekula spoke on behalf of SCEC's Outreach Program and made recommendations to the IRIS committee. These presentations, highlighted by contributions from Robert Ridky, Mike Mayhew, Leonard Johnson, Trish Morse, and Nora Sabelli, all of the NSF, added insight on planning for and focusing its efforts.

The large group (approximately 30 people) broke up into smaller brainstorming groups, using what had been presented as a guide to outline the most significant tools IRIS can use to make a lasting impact on seismology and earth science education. Addressing IRIS's strengths and capabilities, the group documented a list of possible endeavors in the areas of teacher preparation and professional development, data accessibility, internship programs, development of web materials, and the support of the National Science Education Standards. For the first time, the standards recognize earth science as a formal category of study. Issues of scale, span, and context of projects were overarching concerns.

After ideas were compiled and presented, the group broke up again and wrote the first drafts of a formal plan addressing (1) rationale, scope, and purpose; (2) objectives and plan; (3) relations with other science education and national programs; and (4) evaluation and assessment.

Although still in the planning stages, the program has achieved a sense of direction through this workshop. For more information, please refer to the IRIS web site: WWW.IRIS.EDU. The SCEC Community would like to extend best wishes and offers the hand of partnership to this effort.

The serene Airlie Resort was the host site for the IRIS education and outreach workshop.

Photo: Sara Tekula

USGS News

Group to Reevaluate SF for Quakes

The USGS at Menlo Park is beginning Working Group 99, a reevaluation of Bay Area earthquake probabilities. The group's report will be issued in October 1999—the tenth anniversary of the Loma Prieta earthquake. There will be working groups on source characterization, moment budget / background earthquakes, time dependence, and calculations. Tom Henyey, SCEC's center director, will represent southern California in this effort.

FEMA News

Earthquake Protection Grant for Southern California Schools Approved

FEMA recently announced that it will provide more than $10.7 million for school mitigation projects to protect children and reduce damage from future earthquakes in southern California. The funds, allocated from the FEMA Hazard Mitigation Grant Program, are targeted to seismically retrofit and strengthen public and private facilities qualifying for the program. To date a total of more than $360 million in federal disaster money has been approved for earthquake preparedness projects throughout southern California as a result of the 1994 Northridge earthquake.

The FEMA mitigation grant program provides 75-percent funding to state and local entities for cost-effective projects that help to make communities safer from future disasters. More information is available on the FEMA Web site: WWW.FEMA.GOV.

New Name, New Logo

NCEER Is Now MCEER

MCEER

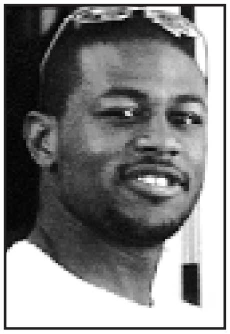
MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

MCEER (formerly NCEER) recently unveiled its new logo, reflecting both the nature of its work and the fact that it is no longer the only national center for the support of earthquake engineering.

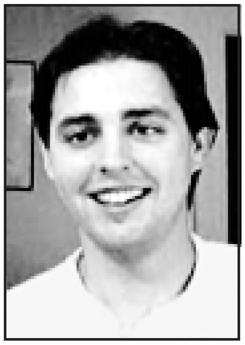
Eight Undergraduate Scholars Chosen for SCEC Summer

Internship Program Coordinator Mark Benthien recently announced the newly selected participants for the SCEC Summer Internship Program, now entering its fifth year. We highlight here the students, their research mentors, project titles, and personal goals. Unless otherwise noted, the mentor and student are at the same institution.

Safaa Dergham, geology major at California State University Long Beach will be working with Sally McGill, CSU San Bernardino. The name of Safaa's project is "Paleoseismic Studies of the San Andreas Fault in the San Bernardino Area." Safaa writes, "My plan is to get a masters degree in geology with a geophysical and seismological emphasis. Once I receive my degree, I would like to get a job that allows me to apply and expand my knowledge in the field, and get some real-life practice. However, my ultimate and eventual goal is to get a Ph.D. in seismology and find cheaper ways to study and predict earthquakes and their behavior."



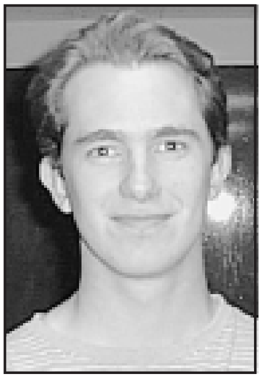
Leland Green, geological sciences major at UC Santa Barbara, will be working with Craig Nicholson. The name of Leland's project is "Development of an Interface for 3-D Visualization of SCEC Earthquake Data on the World Wide Web." Leland writes, "I have realized over the past few years that in order to succeed, I must develop a variety of skills. Keeping this in mind, I have tried to learn skills that are outside the field of geology but still have relevance to geology. This project will allow me to apply the skills that I learned in Java programming class last quarter to my field of study. It will also give me a chance to learn more about seismology and the ways in which information can be presented to educate others about geologic processes. Eventually I would like to become a professor. This project will be an important part of achieving this goal because it will show my ability to use what I have learned to educate others. It will also increase my knowledge of computer applications used in geology and ways in which these applications can be used for education."



Lowell Kessel, geological sciences major at UC Santa Barbara, will be working with Arthur Sylvester. The name of Lowell's project is "Folding and Faulting along the San Andreas Fault, Palmdale, California: Implications for Simple Shear Mechanics and Education of the Public." Lowell writes, "My goal is to contribute to science and public education and my own curiosity by describing the geology, structure, and tectonic evolution of the fault zone within the Palmdale area. I am looking forward to the opportunity to improve my understanding of geology and experience in research with this project. I enjoy independent study and application of my undergraduate training. Furthermore, this project encompasses a field of study I'm interested in—structural geology. Thus, my personal goal is to learn as much about geology as I can and contribute to science and education."

Jacqueline Moccand, environmental studies major at USC, will be working with Ann Blythe. The name of Jacqueline's project is "Geomorphic Mapping and 3-He Chronology of Rock Slide Scarps along the Oak Ridge Fault." Jacqueline applied for the internship "to gain hands-on experience in the field of geology, especially to gain a greater knowledge in the area of seismology and geochronology, both of which I am most interested in. I believe the experience of a SCEC internship will make me a better scientist and give me a greater understanding of how the system works and what is required in the research arena—not to mention make me more marketable for a future job linked to geology."

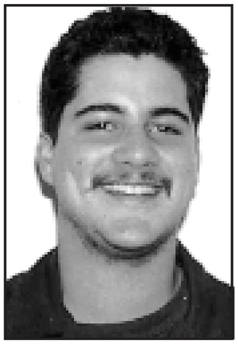
Tracy Pattelena, geophysics major at Pasadena City College, will be working with David Okaya and Nikki Godfrey of USC. The name of Tracy's project is "Velocity Structure in the Los Angeles Basin from Tomographic Inversion of Active Source Data." Tracy writes, "My academic goals are to obtain my BS in geophysics from UC Santa Barbara and then to proceed to graduate school, possibly at USC or Caltech. My career goal is to do what I love—study earthquakes, ground motion, perhaps even volcanoes. My ideal job title would be Research Geophysicist. My personal goal is to contribute to geology through research, discovering what we don't yet know and further investigating what we think we do know, assessing hazards and monitoring potential dangers, to keep the public informed. It is my true passion for this science that drives me."



Justin Rubinstein, applied geophysics major at UCLA, will be working with Paul Davis. The title of Justin's project is "A Study of the Azimuthal Dependence of Seismic Focusing Experienced within Sherman Oaks." Justin writes, "Through this project I hope to create a stronger understanding of geophysical research methods, as well as better my research skills. Professionally, I intend to pursue a Ph.D. in geophysics. I am interested specifically in seismology. Upon completion of my degree, I hope to find a job in the southern California

Internship Program

area, preferably a job in academia. I then plan to continue research involving seismic hazards and the possibility of dependable seismic prediction."



Javier Santillan, geological sciences major at UC Santa Barbara, will be working with Jaime Steidl. The name of Javier's project is "Understanding Ground Motion Variations at the Van Norman Dam Complex Site." Javier writes, "My personal goal is to become proficient in the research process. I have learned that academic research is very difficult and is a skill that must be continually refined. Undertaking this project will allow me to learn many research skills, most notably the use and care of seismic data collection instruments as well as the use of the UNIX operating system for data analysis software. My ultimate academic goal is to earn a Ph.D. in the geological sciences. I plan to attend graduate school in the fall of 1999. I am very interested in structural geology and metamorphic petrology. I believe this project will help me to better understand the research process and broaden my knowledge in the geological sciences. My career goals at present are varied. After completing a Ph.D., I plan to apply for a research position with the petroleum industry or perhaps even do some work with an academic research unit. I am even interested in teaching geology at some point."

Intern photos: Mark Benthien

Lisa Sarma, civil engineering major at Columbia University School of Engineering and Applied Science, will be working with Thomas Heaton at Caltech. Lisa's project is "Investigation of the Coupling between Structures and Ground Vibrations and the Implications on Damping in Buildings." Lisa writes, "I want to apply my knowledge of geophones and geophysics and make a contribution to something useful. I like the idea of getting hands-on exposure to the actual applications and use of the subjects that I have studied in class. As a future civil engineer, I plan to develop and use environmentally sensitive building techniques and, in doing so, increase others' awareness of the importance of conserving the balance between humans and our habitat. I am currently majoring in civil engineering and minoring in earth and environmental engineering. I hope to acquire as much knowledge as I can about both engineering and the environment to make the most positive impact in my work. I intend to pursue a master's degree immediately after I finish my undergraduate education to deepen my understanding of engineering and to concentrate on my areas of interest. These include green building, responsible design, and sustainable development. Following my graduate work, I intend to start a company where I will apply civil engineering to the mutual benefit of humankind and the environment."

Research Program and Funding

1998 SCEC Research Projects

by John McRaney

The SCEC board has completed its review of proposals submitted in response to the 1998 RFP. A list of research projects supported by SCEC in 1998 is shown at the end of this article. SCEC received 150 proposals requesting more than $7.8M. Most were from scientists long involved with SCEC. SCEC has $4.29M in funding for 1998 ($400K less than 1997)—$3.04M from NSF, $1.0M from the USGS, and $250K from Caltrans.

SCEC's Scientific Mission

The center's research objectives are to develop and improve the scientific basis of earthquake hazard estimation. The primary emphases are (1) earthquake potential, or the probability of earthquake occurrence as a function of location, magnitude, and time; (2) rupture dynamics; and (3) ground motion, or complete theoretical seismograms for any earthquake at any site.

Earthquake potential studies include studies to identify active faults and to estimate their maximum magnitudes and slip rates; geodetic studies to measure regional and local strain rates; seismicity observations and focal mechanism studies; theoretical studies that relate earthquake potential to tectonic setting and observable quantities; and hypothesis testing.

Rupture dynamics research includes theoretical and numerical studies of rupture initiation, propagation, and arrest. It includes studies of energy flux, interaction with pre-stress and dynamic stresses, and the stress changes resulting from rupture. Rupture dynamics also includes observation and interpretation of rupture propagation using seismic, geologic, and geodetic data.

Ground motion studies have the objective of predicting the full theoretical seismograms ("time histories") for any combination of earthquake and site. Our objective is to explain the relevant seismic records for past earthquakes, and develop a capability for predicting ground motions from hypothetical future earthquakes. Ground motion calculations should account for complexities in rupture dynamics, wave propagation, and nonlinear site effects. In its research plans for 1998, SCEC will emphasize the interdisciplinary tasks described below.

Seismic Hazard Estimation

The Phase III report (to be completed this year) will describe a suite of seismic source models for southern California, examine models for local site effects, describe the effect of 3-D wave propagation in sedimentary basins, show representative seismograms for scenario earthquakes, and discuss uncertainties and sensitivity to assumptions in seismic hazard estimation. In addition, the report will present several data bases, including an earthquake catalog, fault slip rate table, soil map, and theoretical seismograms.

3-D Seismic Velocity Model

Calculation of complete seismograms requires a model to evaluate P and S velocities at any point in the medium through which seismic waves propagate. Rob Clayton of Caltech will organize an interdisciplinary project to construct a standard seismic velocity model that satisfies a range of geophysical and geological observations, including strong motion seismograms, earthquake travel times, and borehole geologic data. The model will include the effects of sedimentary basins and near-surface sediments. The model will be used to calculate theoretical seismograms and stress increments from earthquakes and tectonic motions.

Stress Evolution

Earthquakes result from stress release on faults, and one desired feature of the Master Model is a facility for calculating the stress accumulation from past earthquakes, tectonics, and viscoelastic stress relaxation. Recent SCEC products, including a catalog of earthquake focal mechanisms for M 6 earthquakes since 1850 and the horizontal crustal deformation map determined from geodetic observations, provide relevant constraints for models of stress evolution. Research on this subject may include calculation of time-dependent stresses, comparison of earthquake occurrence (including aftershocks) with the local stress field, and testing of hypotheses following from the models.

Theoretical studies may involve construction of theoretical models of stress evolution and adjusting parameters for agreement with geologic, geodetic, and seismic data. Observational studies may involve in-situ stress measurements; geological measurements of displacement patterns in past earthquakes; geodetic measurements of strain rate to reveal stress interactions; and measurements of earthquake locations, focal mechanisms, and other observables revealing the relationship between stress and earthquakes.

Southern California Earthquake Center 1998 Funded Projects

Principal Investigator	Affiliation	Group	Project
Mark Abinante & Leon Knopoff	UCLA	G	Model of Dynamic Fractures in a Continuum
Duncan Agnew	UC-San Diego	E	Estimating the Velocity and Strain Field in Southern California Using Gridded Splines
Duncan Agnew	UC-San Diego	E	Fault-Zone Interaction: A Study of the San Jacinto Fault
John Anderson	Nevada-Reno	B	High Frequency Ground Motion by Regression and Simulation
Jill Andrews	USC	I	SCEC Education and Knowledge Transfer Program
Ralph Archuleta	UC-Santa Barbara	I	Portable Broadband Instrumentation
Ralph Archuleta and Alexei Tumarkin	UC-Santa Barbara	I	SCEC Strong-Motion Database SMDB and Empirical Green's Functions Library EGFL
Ramon Arrowsmith and Lisa Grant	Arizona State	C	Historic and Paleoseismic Behavior of the South-Central San Andreas Fault Between Cholame and the Carrizo Plain—Cont
Yehuda Ben-Zion	USC	G	Coupled Self-Organization of Seismicity Patterns and Networks of Faults, and Basis for Evaluating Seismic Risk and Precursors
Yehuda Ben-Zion	USC	D	High Resolution Imaging of Fault Zone Properties
Yehuda Bock	UC-San Diego	E	Infrastructure Support for Southern California Integrated GPS Network (SCIGN)/Permanent GPS Geodetic Array (PGGA)
James Brune	Nevada-Reno	B	Study of the Topping Accelerations of Precarious Rocks in a Profile Perpendicular to the San Andreas Fault for Constraining Strong Motion Attenuation Relationships for Great Earthquakes
Robert Clayton	Caltech	B/D	Using Reciprocal Green's Functions to Model Strong Ground Motion
Robert Clayton	Caltech	D	Real Time Back-Projection of Seismic Array Data
Robert Clayton	Caltech	I	SCEC Data Center Operation
Paul Davis	UCLA	D	Management of LARSE II (UCLA) Stress Modeling and Data Analysis
Paul Davis	UCLA	D	LARSE II: High Resolution Santa Monica Experiment
Paul Davis	UCLA	B	Analysis of Northridge Aftershock Amplitudes and Damage and Santa Monica High Resolution Experiment
Steve Day and Ruth Harris	San Diego State	G	Dynamic Modeling of Earthquakes on Inhomogeneous Faults
Steve Day	San Diego State	B	Effects of Low Velocity Near-Surface Sediments on Long Period Basin Response
Steve Day and Jeffry Stevens	San Diego State	B	Three-Dimensional Simulation of Long Period Ground Motion in L.A. Basin
James Dolan	USC	C	Identification of Potential Paleoseismologic Trench Sites on the San Andreas Fault Between Palmdale and Gorman
James Dolan	USC	C	Paleoseismologic and Slip Rate Study of the Raymond Fault
Danan Dong	JPL	E	Optimal Separation of Coseismic and Postseismic Deformations from Secular Tectonic Motion
Ned Field	USC	A/B	Phase III Summary, PHSA Source Model, and Ground Motion Simulation Comparisons
Bill Foxall	LLNL	A	Epistemic Uncertainty in Geologic Source Chacterization for Probabilistc Seismic Hazard Analysis
Nikki Godfrey, David Okaya, Tom Henyey	USC	D	3-D Contribution from LARSE 1 Data to the SCEC 3-D Velocity Model
Lisa Grant	Chapman	C/A	Neotectonics and Holocene Paleoseismology of the San Joaquin Hills
Rob Graves, Arben Pitarka, Dave Wald	Woodward-Clyde/USGS	B/D	Ground Motion Validation Studies on the Southern California 3D Velocity Model

Rob Graves	Woodward-Clyde	B/D	Setup of 3D Velocity Model: Version 1
Katrin Hafner, John Marqui, Egill Hauksson	Caltech	E	Earthquake-Related SCEC Educational Modules for the WWW
Brad Hager	MIT	E	Continuum Mechanics Models of Blind Thrusts in the LA Basin
Jeanne Hardebeck, Jishu Deng, Egill Hauksson	Caltech	A	Tectonic Stress and Earthquake Hazards
Egill Hauksson	Caltech	D	3-D Velocity Models and Focal Mechanisms
Don Helmberger	Caltech	B	Basin-Edge Structures from Waveform Modeling
Tom Henyey, Paul Davis, Rob Clayton	USC	D	LARSE II
Tom Henyey	USC	I	1998 SCEC Management Operations
Tom Henyey	USC	I	1998 SCEC Visitors Program
Tom Henyey	USC	I	1998 SCEC Workshops
Tom Herring	MIT	E	Geodetic Constraints on Interseismic, Coseismic, and Postseismic Deformation in Southern California
Gene Humphreys	Oregon	A	Fully 3-D Visco-Elastic Faulting Response
Dave Jackson	UCLA	I	Management and Public Relations
Dave Jackson, Yan Kagan, Z. Shen, L. Sung	UCLA	A	Seismic Hazard Estimation
Hadley Johnson	UC-San Diego	E	Geodesy Infrastructure: GPS Data Archiving
Yan Kagan, Dave Jackson, and Z. Shen	UCLA	A	Stress Modeling
Hiroo Kanamori	Caltech	D	Determination of the Slip Plane of Mid-Crustal Earthquakes in Southern California
Hiroo Kanamori & Egill Hauksson	Caltech	I	Enhancement of TERRAscope
Ed Keller	UC-Santa Barbara	C	Earthquake Hazard of the Santa Barbara Fold Belt, Santa Barbara, California
Keith Kelson & John Baldwin	William Lettis & Assoc	C	Paleoseismic Investigation of the Northridge Hills Fault, Northridge Park
Robert King	MIT	E	Support for GPS Analysis
Leon Knopoff	UCLA	G	Model of the Southern California Fault Network
Leon Knopoff	UCLA	G	Nucleation and Breakout of Large Earthquakes
Monica Kohler	UCLA	D	I. Subsurface Imaging of Lithospheric Structures Using Dense Array Data. II. Site Preparation for the Los Angeles Region Seismic Experiment. II Passive Phase
Scott Lindvall	William Lettis & Assoc	C	Paleoseismic Study of the San Andreas Fault at Frazier Mountain
Bruce Luyendyk	UC-Santa Barbara	A	SCEC Standing Committee on Electronic Communication Mini-Workshop: Cataloging and Archiving Information in a Digital Library
Harold Magistrale	San Diego State	B/D	3D Seismic Velocity Models of Populated Southern California Basins
Harold Magistrale	San Diego State	D	Integrated Los Angeles Area Velocity Model
Harold Magistrale	San Diego State	D	Setup of 3-D Velocity Model Version 1
Mehrdad Mahdyiar	VortexRock Consultants	A	Probabilistic Seismic Hazard Analysis of Southern California
Sally McGill	Cal State San Bernardino	C	Paleoseismic Studies of the San Andreas Fault in the San Bernardino Area
Bernard Minster	UC-San Diego	A	Use of Evolutionary Strategies in Seismicity Pattern Analysis
Karl Mueller	Colorado	C	Determining the Geometry of the San Joaquin Hills Blind Thrust: Implications for Earthquake Source Characteristics
Karl Mueller	Colorado	C	Structural Analysis of Active Blind Thrusts and Folds in East Los Angeles
Kim Olsen	UC-Santa Barbara	A/B	Ground Motion Modeling in Los Angeles
Kim Olsen	UC-Santa Barbara	G	3-D Elastic Finite-Difference Simulation of a Dynamic Rupture
James Rice	Harvard	G	Elastodynamic Simulations of Rupture Propagation and Earthquake Sequences along Complex Fault Systems
James Rice	Harvard	G	New Methodology in Computational Seismology for Dynamic Rupture along Complex Fault Systems
Tom Rockwell	San Diego State	C	Paleoseismic Study of the San Andreas Fault at Frazier Mountain
Charlie Rubin	Central Washington Univ.	C	Hydraulic Trench Shoring for Paleoseismic Studies in Southern California
Charlie Sammis	USC	G	Fault Zone Physics
Nano Seeber and John Armbruster	Columbia	A/D	Earthquakes, Faults and Stress in Southern California
John Shaw	Harvard	D/B	Velocity Structure of the L.A. Basin from Sonic Logs and Stacking Velocities
Peter Shearer	UC-San Diego	D	Precision Relocation of Los Angeles Region Seismicity
Zheng-Kang Shen and L. Sung	UCLA	E	Crustal Deformation Velocity Map
Kerry Sieh and Egill Hauksson	Caltech	C/D	Relationship of Aftershocks to Mainshock Rupture of the Landers Earthquake
Kerry Sieh	Cal Tech	C	Characterization of Active Faults in East Los Angles
Kerry Sieh	Cal Tech	C	Characterizing Seismogenic Sources Associated with the Uplift of the San Bernardino Mountains
Kerry Sieh and Doug Yule	Caltech	C	Neotectonic and Paleoseismic Investigation of the San Andreas Fault System, San Gorgonio Pass
Jamie Steidl and Ralph Archuleta	UC-Santa Barbara	B	SCEC Borehole Instrumentation Initiative
Jamie Steidl	UC-Santa Barbara	A/B	Site Response: Completion of Phase III and Beyond
Ross Stein and Dave Jackson	USGS/UCLA	I	SCEC/USGS Workshop on Stress Transfer
L. Sung and Dave Jackson	UCLA	E	Regional GPS Surveys
Lynn Sykes and Jishu Deng	Columbia	A	Development of a Physical Model of Stresses in Southern California
Alexei Tumarkin and Ralph Archuleta	UC-Santa Barbara	B	Integrated Approach to Time Histories Prediction
Mladen Vucetic	UCLA	B	Utilization of the Low-frequency Bedrock Motions Calculated by 3-D Linear Methods in the 1-D Nonlinear SCEC SITE-EFFECTS GIS
Steve Ward	UC-Santa Cruz	A/E	Research toward the Master Model
Ray Weldon	Oregon	C	Analysis of San Andreas Fault Paleoseismic Events at Wrightwood, California
Frank Wyatt and Duncan Agnew	UC-San Diego	E	Pinon Flat Observatory: Continuous Monitoring of Crustal Deformation
Yue-Hua Zeng and John Anderson	Nevada-Reno	B	Simulation of Ground Motion in the Los Angeles Basin

SCEC Research Publications & Abstracts

The following is a list of recent updates to the SCEC database of publications based on SCEC-funded research. SCEC authors must obtain a SCEC contribution number to acknowledge SCEC funding, and in return the paper is added to the SCEC Publication Database. This database is reported to the NSF during each SCEC evaluation. To receive a SCEC contribution number for a recently submitted paper (or for a published paper that did not originally receive a SCEC number), email Mark Benthien (benthien@usc.edu) with the authors, title, publication name, ***abstract*** (very important), and any other bibliographic information. The SCEC number will be returned via email along with the proper NSF / USGS / SCEC acknowledgment statement. The SCEC Quarterly Newsletter now publishes the references only for published articles, no longer listing ones that are submitted, in review, or in press.

207. Abercrombie, R. E., Near Surface Attenuation and Site Effects from Comparison of Surface and Deep Borehole Recordings, *Bulletin of the Seismological Society of America*, 87, pp. 731–744, 1997.

209. Abercrombie, R. E., The Magnitude-Frequency Distribution of Earthquakes Recorded with Deep Seismometers at Cajon Pass, *Southern California, Tectonophysics*, 261, pp. 1–7, 1996.

266. Dolan, J., K. Sieh, T. Rockwell, P. Guptill, and G. Miller, Active Tectonics, Paleoseismology and Seismic Hazards of the Hollywood Fault, Northern Los Angeles Basin, California, *Geological Society of America Bulletin*, 109, pp. 1595–1616, 1997.

Data from geotechnical boreholes and trenches, in combination with geomorphologic mapping, indicate that the Hollywood fault is an oblique, reverse-left-lateral fault that has experienced at least one surface-rupturing earthquake during latest Pleistocene to mid- or late Holocene time. Geomorphologic observations show that the fault extends for 14 km along the southern edge of the eastern Santa Monica Mountains, from the Los Angeles River westward through downtown Hollywood to northwestern Beverly Hills, where the locus of active deformation steps 1.2 km southward along the West Beverly Hills lineament to the Santa Monica fault. Rupture of the entire Hollywood fault, by itself, could produce a M_w ~6.6 earthquake, similar in size to the highly destructive, 1994 Northridge earthquake, but even closer to more densely urbanized areas. Assuming a 0.35 mm / yr minimum fault slip rate consistent with available geologic data, we calculate an average maximum recurrence interval for such moderate events of *~4,000 years. Although occurrence of such moderate events is consistent with the elapsed time since the poorly constrained age of the most recent surface rupture, the data do not preclude a longer quiescent interval suggestive of larger earthquakes. If earthquakes much larger than M_w ~6.6 have occurred in the past, we speculate that they may have been generated by the Hollywood fault together with other faults in the Transverse Ranges Southern Boundary fault system.

318. Ni, S.-D., R. Siddharthan and J. G. Anderson, Characteristics of Nonlinear Response of Deep Saturated Soil Deposits, *Bulletin of the Seismological Society of America*, 87, pp. 342–355, 1997.

356. Dong, D., T. A. Herring, and R. W. King, Estimating regional deformation from a combination of space and terrestrial geodetic data, *Journal of Geodesy*, 72, pp. 200–214, 1998.

An approach of efficiently combining various types of geodetic data to estimate a crustal deformation field is discussed. Three-step analysis procedures, quasi-observations and general constraints (“soft” constraints) are employed to ensure both rigor and efficiency of the combination solution. The corresponding statistical tests for checking the compatibility between different data sets and for calculating normalized root-mean-square (nrms) are developed and addressed. An empirical non-integer degree of freedom is defined to handle the case of general constraint and stochastic perturbation in parameter space, and the increment of “weighted sum of squared residuals” is defined in the form of Kalman filtering. With these developments, we show an example of combining space and terrestrial geodetic data to obtain the deformation field in southern California.

366. Souter, B. J., and B. H. Hager, Faults propagation fold growth during the 1994 Northridge, California, earthquake, *Journal of Geophysical Research*, 102, pp. 11931–11942, 1997.

Geological models of buried thrust faults indicate that fault propagation folds (FPF) form and grow with a geometry that depends on that of the fault (Suppe, 1985; Suppe and Mendeweff, 1990). The displacement gradient fields for faults and kink folds are very similar, and both can be modeled using dislocations. In this paper we test a geological model of the FPF associated with the January 17, 1994, Northridge, California, earthquake to determine whether folding along axial planes inferred from geologic models accounts in part for the coseismic surface displacements measured with Global Positioning System (GPS). We test for coseismic deformation on both the main rupture plane and active axial planes of related folds by inverting for the displacements on dislocation planes in an elastic half-space. A model incorporating two axial planes is preferred to a model with a single rupture plane in a normalized root mean square (NRMS) sense; however, the distribution of axial plane displacements does not correlate with the displacements on the main rupture plane in the way expected for a fault propagation fold. Our results indicate that the deformation associated with folding is too distributed to be resolved on a discrete plane, that the deformation occurs interseismically, or that one or both of the kink bands does not exist. A model of a single elevated plane, which is parallel to, but not coplanar with, the aftershocks, is better in a NRMS sense than the FPF model, indicating that anelastic deformation in the hanging wall may be distributed.

374. Day, S. M., G. Yu, and D. J. Wald, Dynamic Stress Changes During Earthquake Rupture, *Bulletin of the Seismological Society of America*, 88, pp. 512–522, 1997.

We assess two competing dynamic interpretations which have been proposed for the short slip durations characteristic of kinematic earthquake models derived by inversion of earthquake waveform and geodetic data. The first interpretation would require a fault constitutive relationship in which rapid dynamic restrengthening of the fault surface occurs after passage of the rupture front, a hypothesized mechanical behavior which has been referred to as “self-healing”. The second interpretation would require sufficient spatial heterogeneity of stress drop to permit rapid equilibration of elastic stresses with the residual dynamic friction level, a condition we refer to as “geometrical constraint.” These interpretations imply contrasting predictions for the time dependence of the fault-plane shear stresses.

We compare these predictions with dynamic shear stress changes for the 1992 Landers (M 7.3), 1994 Northridge (M6.7), and 1995 Kobe (M6.9) earthquakes. Stress changes are computed from kinematic slip models of these earthquakes, using a finite difference method. For each event, static stress drop is highly variable spatially, with high stress drop patches embedded in a background of low, and largely negative, stress drop. The time histories of stress change show predominantly monotonic stress change after passage of the rupture front, settling to a residual level, without significant evidence for dynamic restrengthening.

The stress change at the rupture front is usually gradual rather than abrupt, probably reflecting the limited resolution inherent in the underlying kinematic inversions. On the basis of this analysis, as well as recent similar results obtained independently for the Kobe and Morgan Hill earthquakes, we conclude that, at the present time, the self-healing hypothesis is unnecessary to explain earthquake kinematics.

377. Ryberg, T., and Fuis, G. S., The San Gabriel Mountains bright reflective zone: possible evidence of young mid-crustal thrust faulting in southern California, *Tectonics*, 286, pp. 31–46, 1998.

During the Los Angeles Region Seismic Experiment (LARSE), a reflection / refraction survey was conducted along a line extending northeastward from Seal Beach, CA, to the Mojave Desert, crossing the Los Angeles basin and San Gabriel Mountains. Shots and receivers were spaced most densely through the San Gabriel Mountains to obtain a combined reflection / refraction image of the crust in that area. A stack of common-midpoint (CMP) data reveals a bright reflective zone, 1-s thick, that dominates the stack and extends throughout most of the mid-crust of the San Gabriel Mountains. The top of this zone ranges in depth from 6 s (~18-km depth) in the southern San Gabriel Mountains to 7.5 s (~23-km depth) in the northern San Gabriel Mountains. The zone bends downward beneath the surface traces of the San Gabriel and San Andreas faults. It is brightest between these two faults, where it is given the name San Gabriel Mountains "bright spot" (SGMBS), and becomes more poorly defined south of the San Gabriel fault and north of the San Andreas fault. The polarity of the seismic signal at the top of this zone is clearly negative, and our analysis suggests it represents a negative velocity step. The magnitude of the velocity step is approximately 1.7 km / s. In at least one location, an event with positive polarity can be observed 0.2 s beneath the top of this zone, indicating a thickness of the order of 500 m for the low-velocity zone at this location.

Several factors make the preferred interpretation of this bright reflective zone a young fault zone, possibly a "master" decollement: (1) It represents a significant velocity reduction. If the rocks in this zone contain fluids, such a reduction could be caused by a differential change in fluid pressure between the caprock and the rocks in the SGMBS; near-lithostatic fluid pressure is required in the SGMBS. Such differential changes are believed to occur in the neighborhood of active fault zones, where "fault-valve" action has been postulated. Less likely alternative explanations for this velocity reduction include the presence of magma and a change in composition to serpentinite or metagraywacke. (2) It occurs at or near the brittle / ductile transition, at least in the southern San Gabriel Mountains, a possible zone of concentrated shear. (3) A thin reflection rising from its top in the southern San Gabriel Mountains projects to the hypocenter of the 1987 M 5.9 Whittier Narrows earthquake, a blind thrust-fault earthquake with one focal plane subparallel to the reflection. Alternatively, one could argue that the bends or disruptions in the reflective zone seen at the San Gabriel and San Andreas faults are actually offsets and that the reflective zone is therefore an older feature, possibly an older fault zone.

390. Zhao, D. and H. Negishi, The 1995 Kobe Earthquake: Seismic Images of the Source Zone and Implications for the Cause of Rupture Initiation, *Journal of Geophysical Research*, 103, pp. 9967–9986, 1998.

To understand what may have triggered the 1995 Kobe, Japan, earthquake (M 7.2) and how the rupture proceeded after initiation, we determined high-resolution 3-D P and S wave velocity and Poisson's ratio structures in the Kobe epicentral area, and relocated the aftershocks with the obtained 3-D velocity model. We used 64,337 P and 49,200 S wave high-quality arrival times from 3634 Kobe aftershocks and local microearthquakes recorded by both permanent seismic networks and portable stations that were set up following the Kobe mainshock. Significant velocity variations of up to 6% are revealed in the aftershock area. We found that areas with high aftershock activity are generally associated with low Poisson's ratio, which may be the strong and competent parts of the fault zone and were apt to generate aftershocks. The Kobe mainshock hypocenter is located in a distinctive zone characterized by low P and S wave velocities and a high Poisson's ratio. This anomaly exists in the depth range of 16 to 21 km, and extends 15 to 20 km laterally. This anomaly may be due to a fluid-filled, fractured rock matrix that contributed to the initiation of the Kobe earthquake. Our interpretation has been supported by many pieces of evidence from hydrological, geochemical, seismological and geophysical investigations conducted at the Kobe earthquake region.

399. Donnellan, A., and F.H. Webb, Geodetic observations of the M 5.1 January 29, 1994 Northridge aftershock, *Geophysical Research Letters*, 25, pp. 667–670, 1998.

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

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

OFF-SCALE

READINGS FROM AUTHORS WHO ARE NOT EARTH SCIENTISTS BUT WISH THEY WERE

"A Bad Earthquake at Once Destroys Our Oldest Associations"

A bad earthquake at once destroys our oldest associations: the earth, the very emblem of solidity, has moved beneath our feet like a thin crust over a fluid; one second of time has created in the mind a strange idea of insecurity, which hours of reflection would not have produced. In the forest, as a breeze moved the trees, I felt only the earth tremble, but saw no other effect. In the city, the houses, from being built of wood, did not fall; they were violently shaken, and the boards creaked and rattled together. The people rushed out of doors in the greatest alarm. It is these accompaniments that create that perfect horror of earthquakes, experienced by all who have thus seen, as well as felt, their effects.

Charles Darwin
Voyage of the Beagle
February 20, 1845

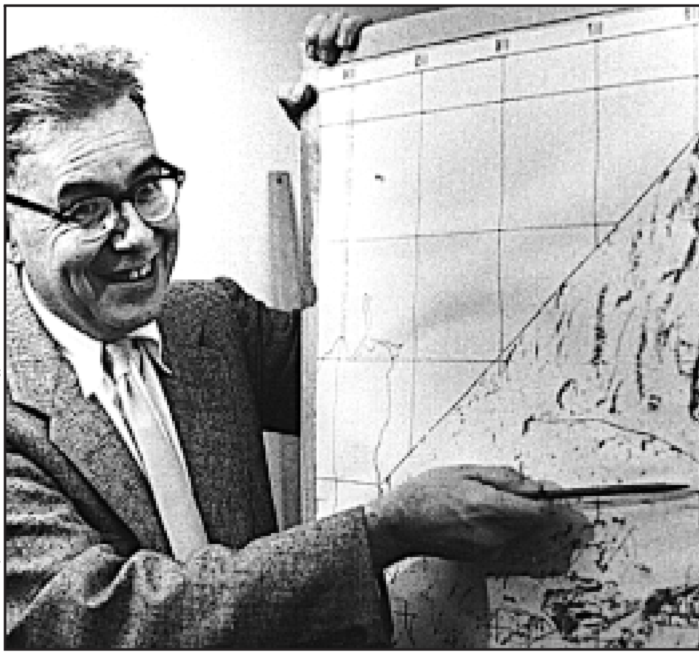


Photo courtesy California Institute of Technology

Charles Richter

Part Two

by Michael R. Forrest

Fear is the fate of those who come to creep—
Some herded by the local imps, like sheep.
Not mine; I know my way, and have no fear;
I have an errand and a purpose here.

—Charles Richter, 1937

In the first part of our two-part chronicle of the life of seismologist Charles Richter, Dr. Forrest looked at Richter's childhood, his education, and the development of the Richter scale. In this final installment, he shows both the man and the scientist in his prime and beyond. Dr. Forrest drew heavily on the Richter papers held by the California Institute of Technology Archives, which generously gave permission for use of the material here.

In his youth, Charles Richter was a nervous and shaky-handed farmboy who found most human interaction painful. During the second half of his life, he developed into one of the nation's best-known seismologists.

The shy farmboy went on to become president of the Seismological Society of America. He received fellowships from the Geological Society of America, American Geophysical Union, Royal Astronomical Society, Royal Society of New Zealand, and American Academy of Arts and Sciences. He received the Medal of the Seismological Society of America. He was author or coauthor of about 100 scientific papers.

Richter's rise in academia was slowed first by the Great Depression and then by World War II. He worked as an assistant professor of seismology at Caltech from 1937-47. After the war, he was promoted to associate professor. It wasn't until 1952 that Richter became a full professor. Coincidentally, because the M 7.5 Kern County earthquake hit that same year, funds appropriated for earthquake science at Caltech were greatly increased. Years later in a letter to Hugo Benioff, he asked, "Wonder what we would be doing now without the Kern County earthquake in 1952."

The Kern County event occurred on July 21 on the left-lateral oblique reverse White Wolf fault, 23 miles south of Bakersfield. It was the largest earthquake in southern California since the 1872 Owens Valley earthquake. It shook Reno, San Francisco, Los Angeles, and San Diego, causing twelve deaths and $50 million in property damage. The earthquake and its aftershocks damaged hundreds of buildings, twisted rail lines, and devastated farmland by breaking irrigation channels and changing groundwater flow. The rupture area still has slightly higher-than-average background seismicity, which may be due to continuing aftershocks. The earthquake was the first of three (including the 1987 Whittier Narrows and 1994 Northridge events) in the second half of this century to demonstrate the possibility of damaging earthquakes on faults with little or no surface expression.

"This event had the normal effect of earthquake disasters on seismology; after it, means became available to expand both in terms of equipment and of personnel," wrote Richter of the event. Fortunately for the seismologists of that time, they were deploying field instruments to monitor a nearby quarry blast when the earthquake hit. "In a few weeks, more significant data bearing on earthquake mechanism and local structures were accumulated than in the preceding 20 years."

Immediately after the earthquake, Richter rushed to deploy more seismometers as well as to analyze, interpret, and archive the accumulating data. Though Richter generally was enthusiastic about fieldwork, his coworkers on this and other trips would sometimes steer him to other tasks, such as making dinner. "Charles may have been a genius in many ways, but he was anything but a mechanical genius," said Clarence Allen of his mentor, remembering (from later fieldwork in Mexico) "several bright blue flashes in his attempts to get various wires connected."

Business of Earthquakes

In 1957, Frank Press became director of Caltech's seismological laboratory. Because of the growth in staff and equipment following the Kern County earthquake, the lab was moved into the Thorsen Mansion in San Rafael. The new lab was actually a true millionaire's Spanish house. It had decorated ceilings, marble floors, wrought-iron balustrades, and flagstone courtyards. The dining room became a library. Blackboards were affixed to the walls of former bedrooms. Bathtubs were covered with plywood so that records could be stored there.

A tunnel under the house was converted to an instrument vault. Benioff and Press both converted bedrooms into offices. Kei Aki, SCEC's cofounder and first science director, used the kitchen. A breakfast room was converted into Richter's office. A note attached to the front of his desk read "You have a theory, I have a hypothesis, but he is just guessing!"

Not the tidiest man, Richter was said to have the habits of a teenager. According to one colleague, "He works at a cartoonist's idea of a desk." However, Richter always seemed to know in which stack and at roughly what level to find a paper he needed.

The new laboratory staff had its first meeting in December 2, 1957. Its first lunch was held in a beautiful convention hall, the decor of which suggested a meal of "champagne and caviar" to one attendee. In reality, everyone ate what they always ate: sack lunches. Richter would work at this mansion-lab until his retirement.

Richter's primary job in the lab was to archive earthquake data. He worked in a large measuring room studying seismogram after seismogram, hour after hour.

"He read the arrival times of the earthquake waves at each station off the seismograms with a ruler and magnifier, and wrote the results on 5-by-8 index cards specially printed with a form to receive the data. We have about 30 file cabinets full of these, covering the period 1932 through some time in the 1980s." says Caltech seismologist Kate Hutton.

"The earthquakes were located on a map, using a compass. Measurements from each recording station tell the distance from the quake to the station, so readings from three stations give three compass settings and pinpoint the epicenter. More than three is better." When it was readable, Richter and his crew also read the amplitude, or peak deflection, of each quake at each station. This was the basis for the magnitude scale. Each of the stations was equipped with at least one Wood-Anderson seismograph, which was the standard of the day for recording the high-frequency energy of local earthquakes.

"Aside from magnitude he also looked at different phases. He was very good at looking at the different wiggles coming in," recalls USC seismology professor Leon Teng. "He would take the seismograms of a large earthquake—M 6 or M 7—with a very long time series, and he would be able to say 'this is PKP' or 'this seems to be exactly the same seismogram as one I saw five years ago.'" Teng also remembers that Richter could tell that an event was caused by a blast from a certain quarry or originated in the south Pacific—all by looking at squiggly lines.

When large earthquakes occurred, Richter would sit in a chair with the lab's telephone in his lap so that only he could answer the calls. Some detractors suggested he did this to promote himself. Actually he was doing his job: gathering information, locating earthquakes, and making the data available as fast as possible. He also didn't think that anyone else armed with only preliminary information could answer calls from the press as well.

> "In one sense, we can already predict earthquakes sufficiently for practical purposes. We know where the areas of danger are and what structures in those areas are unsafe." (Richter)

In the lab's early days, there were maybe 15 seismometers recording earthquakes for all of southern California. The data from all the stations were not always available quickly. In those conditions, his estimating skills were more important than they would be today.

In the same way that the southern California public today has grown comfortable hearing from Lucy Jones (USGS) or Kate Hutton (Caltech) after a significant earthquake, Richter was the seismologist of choice in the 1950s and 1960s. Old-time Angelino earthquake fans will tell you—with great passion—that he was actually more famous throughout the southland in his day than any seismologist is now.

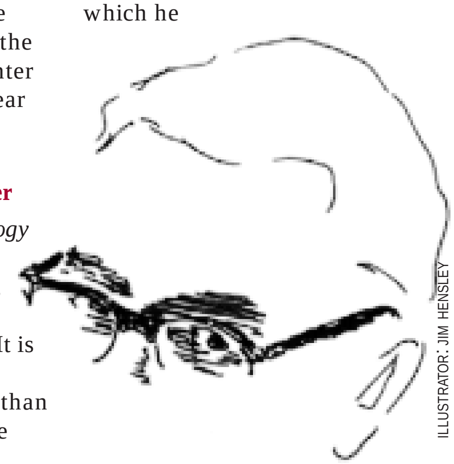
The public and the press loved him. The media generally didn't want to hear from anyone other than Richter. With his facial twitch, bird-like nervous energy, odd voice, serious demeanor, dry wit, encyclopedic memory, absolute mastery of the seismogram, intense eyes, and his sharp, flawless, definitive pronouncements on things seismological, who'd want to hear anyone else? Even after he retired, the press preferred calling Richter after a big earthquake to hear his pontifications.

One of the Best Books Ever

In 1958, *Elementary Seismology* by Charles Richter was published. "In my opinion, Charles' greatest contribution to science is his book. It is sometimes thought of as a textbook, but it is far more than that; it is a truly remarkable compendium of almost everything seismological, with a strong emphasis on field aspects of the science. Is there a seismologist in the world who does not have this book on his or her shelf? And is there anyone among us who does not refer to it occasionally, despite its present 30 year age?" wrote Clarence Allen some years after Richter's death.

"Richter was a keen observer, a man of letters, an excellent linguist," says Kei Aki, who believes the book is one of the best ever written on earthquakes. The book, originally written from Richter's introductory earthquake letters, reflects both his voracious reading habits and considerable writing experience. It was used for many years in Richter's elementary seismology classes and after he retired, but it is no longer in widespread use. Compared to more modern texts, it reads like an encyclopedia, and, of course, seismology has exploded with new data and information since Richter's day.

Richter—as a child—read everything he could get his hands on. He read in English and seven other languages. He particularly loved science fiction. Richter himself wrote a significant body of poems, essays, letters, and journals from his twenties. Richter even worked on several novels, including *House on a Bridge*—which he



ILLUSTRATOR: JIM HENSLEY

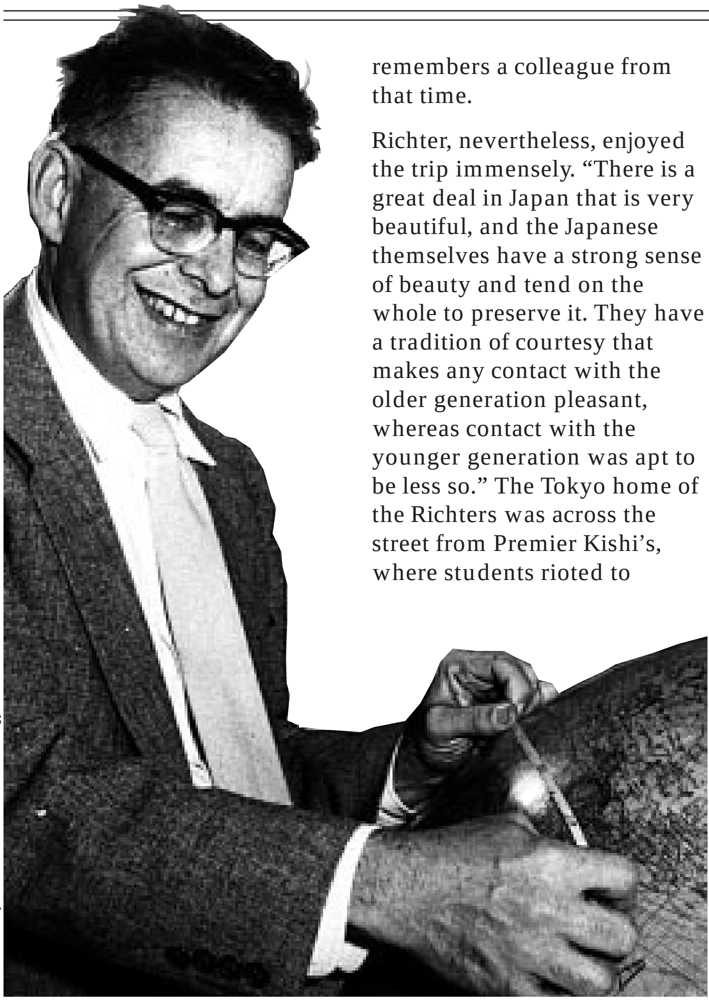


Photo courtesy California Institute of Technology

Charles Richter demonstrating his low-tech methods of measuring the world.

envisioned as one of a quartet. The book follows four characters through life. Unfortunately, he never finished his novels.

Some who heard Richter lecture publicly on seismology remember him fondly. He could make wry comments that would send audiences into fits of laughter. Others remember his seismology classes in the 1960s, when he had tenure and was getting a bit older, as dry and somewhat disorganized.

In 1959, Richter traveled to Tokyo University, where he was a Fullbright research scholar for a year. It was the only time he left Caltech. He never took another sabbatical. “He was worried during the whole time he was away in Japan. He thought California couldn’t do without him,” remembers a colleague from that time.

Richter, nevertheless, enjoyed the trip immensely. “There is a great deal in Japan that is very beautiful, and the Japanese themselves have a strong sense of beauty and tend on the whole to preserve it. They have a tradition of courtesy that makes any contact with the older generation pleasant, whereas contact with the younger generation was apt to be less so.” The Tokyo home of the Richters was across the street from Premier Kishi’s, where students rioted to protest a proposed visit to Japan by President Eisenhower.

When Richter came back from Japan, he was so enthusiastic about his visit and Japanese culture in general that he spent an entire lecture of his graduate seismology class discussing the Japanese language and characters, writing many on the blackboard.

In the early 1960s, Richter gave a number of talks to different groups in which he said that buildings in Los Angeles shouldn’t be built over ten or 12 stories (also more recently suggested by Caltech’s Tom Heaton). At the time, there were no real high-rise buildings in downtown Los Angeles. Our skyline would look radically different had Richter’s ten-story ceiling been heeded. The skyline began to change, and as time went by, when Richter saw what could be done with computer analysis, he became more comfortable with the ever-growing steel, concrete, and glass towers.

> “Toward the mitigation of the disastrous consequences of earthquakes, there could be no more promising step than to organize an international exchange of experience and ideas.” (Richter)

A Private Life

In the mid 1930s, Richter and his wife, Lillian, joined the Fraternity Elysia, a nudist organization, beginning a hobby he would combine for many decades with another activity he loved—hiking. In the tradition of Whitman, Richter would don his backpack and hike for weeks at a time in the high Sierra. On these rambles, he would write poetry and reflect on life, science, and nature.

In the 1960s, as Richter was becoming the grand old man of seismology, he had a seismograph installed in the living room of his house. Lillian “was a little upset at first,” said Richter, “but it was received enthusiastically by her girl friends. It makes a wonderful conversation piece at parties. Now, she wouldn’t be without one.”

The seismograph was a convenience for Richter. Reporters would call him after a tremor, and he could simply amble into the living room, look at the seismograph, and tell the reporter something about the shock.

Music was a great love of Richter’s. Though some of his contemporaries report that Richter had no feel for music—even disliked it—he was passionate about it. He seemed to prefer listening to a record or radio rather than watching an orchestra because he could control and focus on the musical experience more successfully. “Watching the motions in the orchestra may indeed have a hypnotic effect resulting in increased sensibility and even bringing about a feeling of enthusiasm which may or may not be justified,” wrote Richter in a letter to Leon Knopoff in 1963 (it’s unclear whether it was ever sent). “I recall a Heifitz recital in Los Angeles when he and I were much younger. His presentation was utterly cold, technical and supercilious [as if to say] ‘anything is good enough for these peasants’—and he was right; they applauded anything and everything. I could not get out of the hall soon enough.”

Retirement

Though Richter was still subject to bouts of almost debilitating depression, which had plagued him for much of his life, many people perceived a mellowing once he retired in 1970. They found him more approachable. He is said to have laughed a bit more. He became a beloved elder statesman of seismology, and the role suited him.

His retirement party at Thorsen Mansion included the faculty and staff at the time, very few old timers. As with most retirements, it was a bit anticlimactic and predictable, except for a clever song sung by colleagues and students. “The Richter Scale” was written by Caltech professor J. Kent Clark. The song infuriated Richter, who had a well-developed, if dry, sense of humor about a great number of things—except his own science apparently:

> It measured 1.2 on the Richter Scale,
> A shabby little shiver;
> 1.2 on the Richter Scale—
> A queasy little quiver . . .

In 1972, Richter helped found Lindvall, Richter and Associates. The consulting firm was the brainchild of Eric Lindvall, father of SCEC scientist Scott Lindvall and son of the dean of engineering at Caltech. "It became obvious to me that something should be done about earthquake protection," says Lindvall after the 1971 Sylmar earthquake.

LR&A would complete seismic hazards analyses for building sites or act as consultants in litigation involving earthquake damage. "Richter was active in the firm until the last year or two before his death. He'd be in the office two or three times a week. When we'd have a review of existing facilities or of a seismic hazard, he would write a chapter on the seismology. When Dr. Richter said something, there weren't many people who would argue with him," recalls Lindvall.

With regard to his science, Richter was incorruptible. Because of this, lawyers avoided using him as an expert witness. He never took sides; he would present his findings and analyses. When lawyers tried to shape his testimony into a more favorable presentation, Richter would refuse to change a word.

Richter's method was at least two decades ahead of his time. Unlike most scientists involved in hazard analysis at that time, he wouldn't consider only the known faults and the earthquakes they might produce in his analyses. Richter always assumed one of M 6 or greater could occur directly under a given site on an unknown fault. Most developers rejected that suggestion at the time. Today, scientists who study the area concur on a probabilistic analysis that reflects Richter's earlier hypothesis.

One of many anecdotes Lindvall remembers as typical of Richter occurred in the 1970s when the city of Downey asked him to about whether a fluid-injection oil-recovery project would cause earthquakes.

He gave them a concise answer: it wouldn't—it's too shallow. When he finished, one of the council members said, "Thank you, but could you put it in terms that we can understand. Is it 90 percent sure that nothing would happen, or how would you phrase it?" After 10 seconds, 20 seconds, Charlie said, "If I told you that it was 95 percent, you wouldn't know what that meant either." There wasn't another question about earthquakes.

Lindvall still misses his old colleague. "Personally, we weren't very close. But from a scientific, technical, and professional standpoint there was always something new."

Reflection

"I've been working fewer hours since retirement, though not by choice. I've found Father Time has caught up with me," said Richter of his retirement. After retiring, Richter, using the penname John Florio, published quite a bit of his poetry in a small local newspaper.

His poetry mirrored the more whimsical and philosophical corners of his psyche, at times displaying the sentiments most people would not have thought him capable of feeling, much less expressing, as in "City Park in April" (1973):

> Always,
> The tiny fears—
> Will there be daffodils?
> Have tulips been set out again
> This spring?
>
> Machines
> Grind angrily
> Beyond a flimsy fence.
> Too much, already, that they scare
> The birds.
>
> Gardens
> Should range abroad,
> Not be confined like this—
> This jeweled island in a sea
> Of dust.

In his later years, Richter seemed to have had few regrets other than a common one—not having made the most of time spent with old friends and mentors. For example, he regretted not having attended as many lectures at Caltech as possible in his younger days—such as those given by Albert Einstein.

Richter wrote warmly of such figures from his past as Hugo Benioff, Harry Wood, and the mathematician Harry Bateman, of whom Richter tells several humorous stories that demonstrate both Bateman's feats of mathematical genius and Richter's appreciation. Gutenberg does not fare as well in Richter's writings.

On the last day of September 1985, Richter died in a convalescent home from congestive heart failure. He was 85. From an Ohio farm to Caltech, from reciting the names on his mother's flash cards in three languages to co-inventing the field of seismology, from painful shyness to meeting Einstein and Millikan—a remarkable journey. The fire and the fury of a passionate, brilliant, wise, unconventional man passed into silence.

He was buried in Mountain View Cemetery near Lillian who had died of cancer in 1972. In the same cemetery are a governor of California and a friend of Abe Lincoln. Richter's plot lies far from the ornate nineteenth-century gravestones and mausoleums. Richter probably had enough money to have his wife and himself placed in a prominent spot in the cemetery. Instead, he chose a private, nondescript corner for his bones to be rattled by the P, S, and L waves he loved to study. Unlike many of the nearby grave markers—which are covered with mud and overgrown grass—it appears as though someone visits his plot, trims the grass, and wipes the earth off his name.

EPILOGUE

Richter and Northridge

In a little-known jest of fate, Richter became a victim of the Northridge earthquake. After he died, his nephew inherited many of Richter's personal belongings. They included rare books of science, art, and literature; a beautiful cherry-wood desk; and irreplaceable objects like home movies and a diary that described Richter's meeting with Einstein.

Richter's nephew thought he was prepared for an earthquake, his awareness heightened by many interactions with his uncle. The house was stocked with emergency food and water and covered by earthquake insurance. After the 1994 Northridge earthquake, a quake-related fire burned down the nephew's Granada Hills home. The family escaped, but Richter's belongings were destroyed.

The author is deeply indebted to the Caltech Archives for access to the Richter papers and permission to quote and refer to them throughout both articles. The author also thanks a great number of people who prefer not to be mentioned as well as those quoted. Additional thanks to Mary Melton and Ann Connors of the *Los Angeles Times Sunday Magazine*.

Foreign Earthquake Studies

Central American Workshop in

By Hugh Cowan

A work session in paleoseismology was recently held in Nicaragua as part of a seismic microzonation project in the capital, Managua. Seismic microzonation for Managua forms part of a Central American regional program of earthquake hazard reduction, which is funded by the Norwegian Agency for Development Cooperation (NORAD) and coordinated through a regional secretariat, Centro de Coordinacion para la Prevencion de Desastres Naturales en America Central (CEPREDENAC).

Since the late 1980s, the countries of Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama have collaborated in a program of natural hazard assessment and disaster preparedness, which is intended to avert future suffering and economic losses such as those caused by earthquakes in El Salvador (1986), Guatemala (1976), and Nicaragua (1972).

A recent component of the CEPREDENAC program has been the introduction of paleoseismology to seismic hazard assessment of major active faults. The first study of that kind was conducted in April 1997, adjacent to the Panama border in southern Costa Rica. The recent Managua workshop involved a larger number of participants from all countries in Central America. We were fortunate to attract several experienced instructors from the U.S. and Europe.

Additional sponsorship and logistic support was provided by the International Lithosphere Program (ILP) and the local host organization—Instituto Nicaraguense Estudios Territoriales.

> The recognition of prehistoric surface ruptures on faults with no historic record of movement represents an important contribution to the local perception of seismic hazard, which hitherto has been strongly influenced by the historic events.

Why Managua?

The capital of Nicaragua, Managua, is located at the Central American volcanic chain on the southern shores of Lake Managua. The NW-SE trending volcanic chain exhibits a pronounced offset of about 15 km to the south across Managua—from Volcan Momotombo on the northwest shore of Lake Managua to Masaya Caldera southeast of the metropolitan area.

Within the step-over region, which includes metropolitan Managua, a closely spaced system of strike-slip and oblique-normal faults shows cumulative evidence of repeated late Quaternary movement along a north-northeast trend. Twice during this century, Managua has suffered severe earthquake damage associated with the rupture of this local fault system.

On March 31, 1931, a shallow earthquake of M 5.3-5.9 produced surface rupture along a NNE-trending fault (Falla Estadio) in the western part of Managua. The urban population at that time was around 40,000. About 1,000 people were killed. Central districts were severely damaged due to the collapse of buildings and by the fires that followed (Sultan, 1931).

Forty years later, the population of Managua had swelled to around 500,000, and the city was struck again by an earthquake (M_b 5.6, M_s 6.2) on December 23, 1972. The impact of the 1972 event was devastating. Structural collapse and fire destroyed the western sector of the city, including the downtown area: 11,000 people died and 20,000 were injured. More than 200,000 people were left homeless, and the economic cost in that year alone exceeded 40% of the GNP.

The 1972 earthquake ruptured four NNE-trending faults, of which the largest is Falla Tiscapa. The sense of displacement was left-lateral oblique-slip, with aggregate horizontal movements in the range 2 to 38 cm, and a minor vertical component on three of the four faults (Brown et al, 1973). Aftershocks defined a rupture zone extending several kilometers beneath Lake Managua, <8-10 km deep.

Hazard Assessment and Urban Planning

In the years following the 1972 earthquake, considerable work was undertaken to map the local faults and evaluate the seismic hazard in Managua and nearby centers. Consultants performed much of that work, incorporating state-of-the-art industry practices. Significant accomplishments during the 1970s included the identification and mapping of major faults in metropolitan Managua and the development of a logical framework for fault hazard evaluation in urban planning (Woodward-Clyde Consultants, 1975; Dames and Moore-Lamsa Consortium, 1978).

Many of the consultants' recommendations were enshrined in local planning regulations, but in subsequent years competing priorities (and relative seismic quiescence) meant that little new work was undertaken to evaluate active faulting. More recently, however, both the CEPREDENAC program and local institutions have refocused on natural hazard and vulnerability assessment. Managua, with a current population estimated at 1,000,000, is one of the most vulnerable urban centers in Latin America.

> Managua, with a current population estimated at 1,000,000, is one of the most vulnerable urban centers in Latin America.

Paleoseismology Work Session

The 1931 and 1972 earthquakes were associated with fault

Paleoseismology

ruptures in the western part of Managua, but the longest identified surface faults (Falla Aeropuerto, >20 km, and Falla Cofradia, about 40 km) are, in fact, located in the eastern part of the graben. Neither fault has been associated with historic rupture, yet both Falla Aeropuerto and Falla Cofradia were recently observed to displace young sediments close to the Lake Managua shoreline. Furthermore, Falla Aeropuerto offsets both the modern shoreline and a prehistoric shoreline of Lake Managua.

The Fieldwork

Our fieldwork focused on Falla Aeropuerto in an attempt to quantify the ages of landforms and sediments along the northern section of the fault. The workshop commenced with air-photo analysis of several localities, followed by walk-over surveys to select suitable localities for excavation. Three trenches were subsequently opened along a 300-m section of the fault, and leveling profiles were constructed across all surfaces.

The kinematics of faulting appeared to be dominantly strike-slip, probably left-lateral, with a component of normal offset down to the east. Two paleoearthquakes are inferred from the composite stratigraphy that includes volcanic agglomerate, lacustrine, and fluvial sediments and peat.

Dating of several organic samples is pending, but the faulted horizons in all trenches contained Pre-Colombian pottery (of unknown age), whereas unfaulted horizons in all trenches contained ceramics inferred to be of Spanish-colonial age. We hope to be able to bracket the age of a paleo-shoreline of Lake Managua, which is offset vertically about 2 m across the fault.

The People

The participants worked long days in intense heat with great enthusiasm. There was broad participation among physics, engineering, and geoscience graduates. The fieldwork was supplemented with evening lectures on a variety of topics, including site selection criteria, field techniques, dating methods, recognition of faulting styles, seismic hazard analysis, and sensitivity testing. We concluded a busy week with a tour of the surroundings of Managua, including the Masaya and Apollo calderas.

In summary, the work session was very rewarding both as a scientific investigation and as a training exercise. Furthermore, the recognition of prehistoric surface ruptures on a fault with no historic record of movement (Falla Aeropuerto) represents an important preliminary contribution to the local perception of seismic hazard, which hitherto has been strongly influenced by the historic events.

Training opportunities in paleoseismology and Quaternary tectonics for young Nicaraguan graduates should be required as follow up in order to consolidate the benefits of the workshop. Similar needs exist throughout Central America. We would be interested to hear from persons or institutions that could assist in meeting these needs. For more information concerning participants and references, contact Hugh Cowan: HCOWAN@SINFO.NET.

New Quake Concerns at Nuclear Dump Site

Geologist Brian Wernicke (Caltech) and his colleagues have discovered that Nevada's Yucca Mountain, a proposed site for a federally run nuclear waste dump, is at least ten times more likely to experience an earthquake or volcanic eruption than previously thought.

> Based on GPS information from the satellites alone, the crust near the mountain is heading west-northwest at nearly 2 mm a year—roughly three to four times the average for the Basin and Range region in which Yucca Mountain sits.

The findings, published in a recent edition of *Science*, come at a time of intense debate in Washington over high-level radioactive waste from the nation's 109 commercial nuclear plants.

Federal courts have ruled that the U.S. Department of Energy must take the waste, but the DOE counters that it can't take any before the President approves a permanent site.

To speed the hand-over of waste, both houses of Congress have passed bills that would designate Yucca Mountain as a temporary storage site despite President Clinton's threat to veto any such measure. The study could become the latest rallying point for opposition to Yucca Mountain as a permanent nuclear-waste facility.

Financed with grants from the National Science Foundation and the U.S. Nuclear Regulatory Commission, Wernicke and his colleagues set up ten Global Positioning Satellite (GPS) receivers among the two California fault zones and five receivers in a line that cut across Yucca Mountain. Based on GPS information from the satellites alone, the crust near the mountain is heading west-northwest at nearly 2 mm a year—roughly three to four times the average for the Basin and Range region in which Yucca Mountain sits.

Wernicke acknowledges that answers to questions about the sources of the strain including where and how the strain is most likely to be released would require additional measurements.

Planned seismic- and volcanic-hazard assessments for the DOE's Yucca Mountain project have already been completed, says Richard Quittmeyer, a seismologist involved with the Yucca Mountain project-management team. Yet the study could reopen the discussion about seismic risks at the site. For more information on Yucca Mountain site and the issues and studies concerning it, refer to the following web site: WWW.YMP.GOV.

Calendar

June

21-23—SCEC workshop held in Utah on the physics governing the behavior of earthquakes and faults.

24-26—Western United States Earthquake Insurance Summit, Sacramento, CA. For information, contact Western States Seismic Policy Council: 415-974-6435 or wsspc@wsspc.org.

26-July 1—Disaster Forum '98: Global Partnerships Creating Solutions, Edmonton, Alberta, Canada. For information, email disaster@freenet.edmonton.ab.ca or visit the web site: www.freenet.edmonton.ab.ca/disaster.

28-July 3—Gordon Research Conference on the "Interior of the Earth" at New England College in Henniker, NH. Contact Mike Gurnis gurnis@caltech.edu or John Vidale vidale@ucla.edu. Interior of the Earth web page: www.gps.caltech.edu/~gurnis/gordon.html. Web page for the GRC: www.grc.uri.edu/

July

8-12—IRIS meeting, Santa Cruz: contact Susan Strain: susan@iris.edu. Tentative: SCEC-sponsored education modules to be demonstrated in workshop "Seismo Software for the Classroom."

10-23—Summer school in "Active Faulting and Paleoseismology," Luxemburg. Contact Dr. M. Meghraoui, email: must@irtr.rm.cnr.it.

15—Newsletter 4.2 articles and copy due to editor. Contact Ed Hensley, 916/353-9996.

August

23-28—The XXVI General Assembly of the European Seismological Commission (ESC), Tel Aviv. Conference home page: http://www.geo.iprg.energy.gov.il/sd/esc2.html. ESC home page: http://www.gsrg.nmh.ac.uk/esc/.

September

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

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

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

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

October

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

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

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

November

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

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

December

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

January 1999

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

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

SCEC Notes • SCEC Notes • SCEC Notes • SCEC Notes • SCEC Notes

Bob Yeats of Oregon State University is the 1998 recipient of the Michel T. Halbouty Human Needs Award from the American Association of Petroleum Geologists. The award, presented at the annual meeting of AAPG at Salt Lake City in May, is in recognition of Bob's use of geological data from petroleum-industry well logs and seismic profiles in earthquake hazard mitigation in southern California. Bob's email address is yeatsr@bcc.orst.edu.

Dapeng Zhao used to be a member of the research faculty in earth sciences at USC. Now he's in Japan as of February 1998 as a tenured associate professor at Ehime University. Update your address books for the new associate professor in Matsuyama: zhao@sci.ehime-u.ac.jp. And on the web: http://precision.eng.sunysb.edu/dalian4.

Chris Walls and **Maria Herzberg** recently took staff consulting positions with Earth Consultants International. Both are graduates of SDSU in geology.

Congratulations, Sara. On May 8, SCEC Outreach Education Specialist Sara Tekula was recognized at USC's commencement. Although she officially completed her undergraduate studies in December of 1997 with a B.A. in psychology, this made it "official." Family members traveled from New York to share the experience. Sara is the first in her immediate family to graduate from a four-year college.

Sergio Chavez-Perez graduated last December with a Ph.D. in geophysics from the UNR. He's working now at the Mexican Institute of Petroleum as a research geophysicist specializing in seismic imaging and migration. Email him at sergio@orion.expl.imp.mx

Mark Stirling successfully defended his Ph.D. in April. His thesis was an analysis of the seismic hazard in so. Cal & New Zealand. Congratulations, Mark. We'll look forward to hearing where you go from here. stirling@judson.seismo.unr.edu

Earthquake Information Resources Online

SCEC on the Web
www.scec.org

Earth Sciences

SCEC Data Center

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Seismo-Surfing the Internet

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

USGS Web Sites

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

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

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

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

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

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

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

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

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

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

USGS email addresses

neic@usgs.gov
National Earthquake Information Center

ngic@usgs.gov
National Geomagnetic Information Center

nlic@usgs.gov
National Landslide Information Center

Paleoseismology

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

Active Tectonics

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

GIS Web Sites

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

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

Continued on next page . . .

Online Resources continued

HTTP://WWW.LIB.BERKELEY.EDU/CGI-BIN/PRINT_HIT_BOLD.PL/UCBGIS/
UCB GIS Task Force integrates GIS activities with other resources at UCB campus, recommends GIS services for library

HTTP://WWW.NWI.FWS.GOV/THINKTANK.HTML
GIS Think Tank on problems of digital mapping for users of NWI data

HTTP://FGDC.ER.USGS.GOV/LINKPUB.HTML
List of FTP directories for federal Geographic Data Committee

HTTP://MIS.UCD.IE/STAFF/PKEENAN/GIS_AS_A_DSS.HTML
Paper on how to use a GIS as a DSS generator

HTTP://SPSOSUN.GSFC.NASA.GOV/EOSDIS_SERVICES.HTML
A spectrum of services, some for casual users, some for research scientists, some inbetween

HTTP://WWW.GGRWEB.COM/
Services of information technologies, earth sciences, GIS, GPS, & remote sensing industries

Geodetic Information

HTTP://LOX.UCSD.EDU
This site is the IGPP & Scripps Orbit and Permanent Array Center (SOPAC) and features global (IGS) and regional (SCIGN) continuous GPS archive, SCIGN maps, time series, and site velocities.

GMT

HTTP://QUAKE.UCSB.EDU
Helps make shaded relief maps with GMT. Has catalog of maps produced by Geoffrey Ely at the ICS/UCSB. Downloadable digital elevation model for southern California in GMT-readable (netCDF) format. The grid covers the region 121W 115W 32.5N 35.5N at a resolution of 3 arc sec. You can get to the web page from the ICS home page, then click on Mapping, and then Geoff's Map Catalog.

Preparedness, Disaster Management

HTTP://WWW.BEST.COM/~TRBU/OES/
California Governor's Office of Emergency Services: information on Earthquake Preparedness Month campaign

HTTP://KFWB.COM/EQPAGE.HTML
KFWB Quake Page (by Jack Popejoy)

HTTP://KFWB.COM/CUCAMONG.HTML
KFWB Webservice exclusive: trenching the Cucamonga fault:

HTTP://WWW.HIGHWAYS.COM/LASD-EOB/
The Los Angeles Sheriff's Emergency Operations Bureau

HTTP://WWW.JOHNMARTIN.COM/EQPREP.HTM
John A. Martin & Associates

HTTP://WWW.EERC.BERKELEY.EDU/
Earthquake Engineering Research Center offers extensive, searchable database of abstracts, reports, and other resources. New: "Lessons from Loma Prieta,"with papers, images, and data.

Earthquake Information Sites

HTTP://WWW.EQNET.ORG/
EQNET

HTTP://WWW.TRINET.ORG/
Trinet—the seismic system for southern California

HTTP://ERP-WEB.ER.USGS.GOV/
Recent USGS NEHRP Research Contracts

HTTP://NCEER.ENG.BUFFALO.EDU/ENEWS
Express news, customizable electronic service that alerts readers to earthquake/hazards information selected from the most recent NCEER Information Service News based on a reader's interest profile.

HTTP://WWW.CIVENG.CARLETON.CA/CGI-BIN/QUAKES
Recent quakes (with a great map viewer)

HTTP://WWW.CRUSTAL.UCSB.EDU/SCEC/WEBQUAKES/
Up-to-the-minute southern California earthquake map—latest 500 earthquake locations. Java-enabled browsers only.

HTTP://SMDB.CRUSTAL.UCSB.EDU/
A relational database of information about and access to strong motion recordings.

HTTP://WWW.CONSRV.CA.GOV/DMG/SHEZP/PSHA0.HTML
Probabilistic Seismic Hazard Map, California

HTTP://WWW.ABAG.CA.GOV/BAYAREA/EQMAPS/LIQUEFAC/BAYALIQS.GIF
Bay Area hazard map

HTTP://WWW.WSSPC.ORG
Western States Seismic Safety Policy Council site, an overall earthquake safety information source.

HTTP://WWW.SCECDC.SCEC.ORG/GLOSSARY.HTML#BLIN
Glossary of terms (in progress)

HTTP://WWW.GEOPHYS.WASHINGTON.EDU/SEISMOSURFING.HTML
Seismic Info Sources

HTTP://WWW.SEISMIC.CA.GOV/SSCCATR.HTM
California's earthquake hazard mitigation plan

HTTP://WWW.SEISMIC.CA.GOV/SSCLEG.HTM
Current state and federal bills being tracked by the Commission)

HTTP://WWW.SEISMIC.CA.GOV/SSCSIGEQ.HTM
Seismic Safety Commission—significant damaging earthquakes

HTTP://SHELL.RMI.NET/~MICHAELG/WEEKSREVIEW.HTML
Biweekly earth science review

Internet Discussion Groups

WSSPC-L@NISEE.CE.BERKELEY.EDU
Western States Seismic Policy Council discussion group

EQ-GEO-NET@GSJTMWS8.GSJ.GO.JP
Paleoseismic ListServe

GVN@VOLCANO.SI.EDU
Global Volcanism Network

QUATERNARY@MORGAN.UCS.MUN.CA
Research in quaternary science

SEISMD-L@BINGVMB.BITNET
Seismological discussion list (SEISMD-L)

QUAKE-L@LISTSERV.NODAK.EDU
Earthquake discussion list

SCEC Quarterly Newsletter

a component of the Center's Outreach Program

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

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

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

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

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

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

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

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

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

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

username: scecnewsletter
login: issue34

Have questions? Call, fax, or email:

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

Inside this issue:

Feature Articles

Precarious Rocks 3
Interview: Jean-Bernard Minster 6
Seismicity of the San Joaquin Hills 12
Feature: Charles Richter, Part Two 26

SCEC Departments

From the Directors: Research to Reduce Hazard 2
SCEC News Briefs 16
Summer Interns 20
SCEC's Research Program & Funded Projects for 1998 21
SCEC Research Publications & Abstracts 24
"Off-Scale" 25
Calendar 32
SCEC Notes 32
Earthquake Information Resources Online 33

SCEC Quarterly Newsletter

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

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

Contributing writers:
Jill Andrews, SCEC
Mark Benthien, SCEC
Thomas Henyey, USC/SCEC
David Jackson, UCLA/SCEC
Sara Tekula, SCEC

Photography:
Jill Andrews, Sara Tekula, Lisa Grant, Mark Benthien, Michael Forrest, Caltech Archives

Editorial review:
Linda Townsdin

Richter Photographs:
Courtesy California Institute of Technology Archives

Richter Illustration:
Jim Hensley

Cover:
adapted from photo by James N. Brune

FOR SUBSCRIPTION INFORMATION—SEE PAGE 35

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

ADDRESS CORRECTION REQUESTED