Southern California Earthquake Center

Quarterly Newsletter
Fall 1995

Volume 1, Number 3

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Preliminary Results from the Los Angeles Region Seismic Experiment (LARSE)

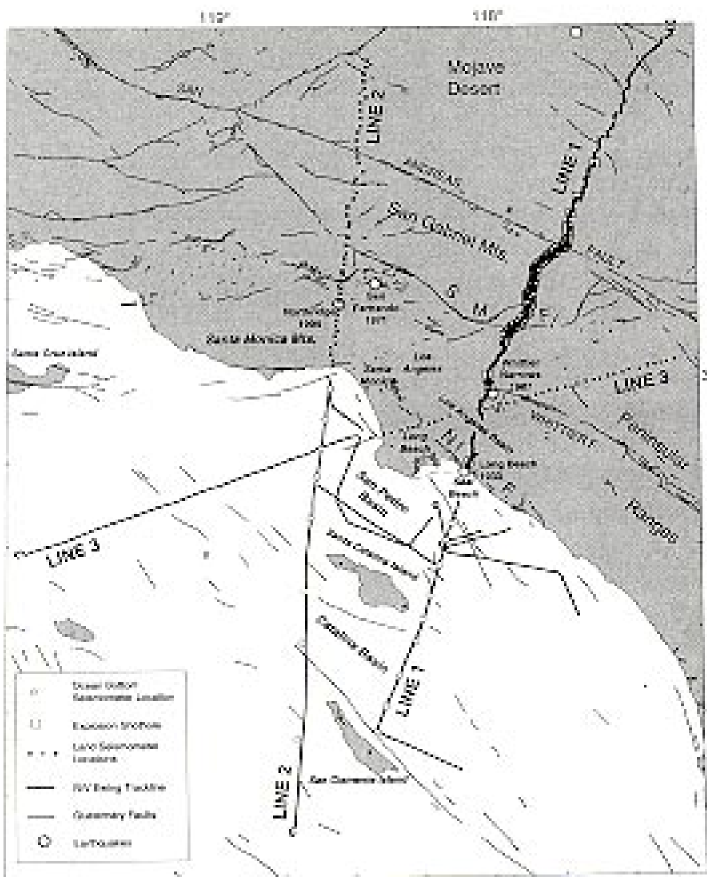

Figure 1. Fault map of Los Angeles region (from Jennings, 1975) showing locations of sources and receivers for October 1994 LARSE airgun and explosion surveys. CBF, Catalina basin fault; SPBF, San Pedro Basin Fault; PVHF, Palos Verdes Hills Fault; NIF, Newport-Inglewood Fault; SMF, Sierra Madre Fault Zone.

Introduction: Why LARSE?

Recent damaging earthquakes in the Los Angeles region have highlighted earthquake hazards associated with thrust faulting. As a consequence of the "bend" in the San Andreas fault north of the Los Angeles region (see Figure 1, opposite), tectonic strain in southern California is partitioned in the earth's upper crust among *thrust faulting*, chiefly in the Transverse Ranges, *strike-slip faulting*, chiefly in the region south of the Transverse Ranges, and *folding* in both regions. Coupling of upper-crustal deformation to lower-crustal and mantle deformation is still poorly understood, although some progress has been made using geodetic data and lithospheric imaging. There is an urgent need to understand how the accumulating strain is likely to be relieved spacially and temporally so that preparations can be better made by emergency planning agencies, city planners, and engineering design advisory agencies. This need requires a fundamental knowledge of the crustal structure in southern California–the *subdivision* of the crust into blocks, the *properties* of those blocks, and the *coupling between* the blocks–and also a knowledge of how stress is being applied to this structure.

To address the need for knowledge of crustal structure, the U.S. Geological survey and the Southern California Earthquake Center have initiated a program of seismic imaging known as the Los Angeles Region Seismic Experiment (LARSE). Preliminary images from the LARSE have illuminated a number of the

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From the Center Directors...

Keiiti Aki
Science Director

Thomas Henyey
Executive Director

The Case for a National Earthquake Hazards Reduction Program

The population in the world's "earthquake belts" is increasing at a rapid rate. This is because the same geologic processes responsible for earthquakes also produce some of the world's most desirable and valuable real estate. But often with few resources at their disposal, large segments of these populations are erecting structures too feeble to withstand even modest shaking. In the United States, many such structures remain from earlier times or are continuing to be built without a full understanding of the earthquake hazard. Even moment frame steel and wood frame structures, once believed by engineers to be virtually invincible to the strongest earthquake shaking, are turning up with serious problems, resulting from both design flaws and poor quality of construction. In cities of second and third world countries such as Mexico City, Istanbul, Cairo, Mindanao, Jakarta, and Athens, the population at risk mounts sharply and irrevocably each year, while in cities such as Tokyo, Taipei, San Francisco, Los Angeles, Salt Lake City, Seattle, Vancouver, Naples, and Nice we rely on a complex and delicate infrastructure that is highly vulnerable to strong earthquakes. So just as we continue to fight the major diseases of our time, we must continue to wage war on the risks from earthquakes and other natural hazards.

Almost everything we now know about earthquakes and how to deal with them has been learned from the laborious work of several generations of scientists and engineers who were fascinated by the awesome power of earthquakes, and were intrigued by the possibility of forecasting both their occurrences and their effects, in order to warn populations and harden them against potential destruction. For the past 25+ years, the National Earthquake Hazards Reduction Pro-

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What Is the Southern California Earthquake Center?

The Southern California Earthquake Center (SCEC) actively coordinates research on Los Angeles region earthquake hazards and focuses on applying earth sciences to earthquake hazard reduction. Founded in 1991, SCEC is a National Science Foundation (NSF) Science and Technology Center with administrative and program offices located at the University of Southern California. It is co-funded by the United States Geological Survey (USGS). The Education and Knowledge Transfer programs are co-funded by the Federal Emergency Management Agency (FEMA). The Center's primary objective is to develop a "Master Model" of earthquakes in southern California by integrating various earth science data through probabilistic seismic hazard analysis. The SCEC promotes earthquake hazard reduction by:

- Defining, through research, when and where future damaging earthquakes will occur in southern California;
- Calculating the expected ground motions; and,
- Communicating this information to the public.

To date, SCEC scientists have focused on the region's earthquake potential. Representing several disciplines in the earth sciences, these scientists are conducting separate but related research projects with results that can be pieced together to provide some answers to questions such as *where* the active faults are, *how often* they slip, and *what size* earthquakes they can be expected to produce. Future work will consider seismic wave path effects and local site conditions for developing a complete seismic hazard assessment of southern California.

NEHRP *continued from Page 2 ...*

gram (NEHRP) has been the foundation of this country's research efforts.

The most important record we have is that of past earthquakes, culled from a global seismic network initiated about the beginning of this century. The magnitude-frequency distribution of earthquakes, first extracted from the global data in the 1940s, is now one of the cornerstones of worldwide seismic hazard estimation. However, statistics on the largest, most damaging earthquakes are inadequate in most seismically active regions in the world. A basic, still unanswered question is whether such events in a given region tend to cluster in time or are largely quasi-periodic.

Fundamental data on the geometry and slip rates of faults have come largely from geologic investigations–mostly carried out in the last two decades. These data are crucial for extending the historic seismic record back in time to improve the statistics on large earthquakes as well as for documenting which faults are most active. This work is exceedingly time consuming per data point, and as such we have only scratched the surface in our understanding of slip rates and maximum rupture lengths–both critical parameters for seismic hazard assessment.

"...just as we continue to fight the major diseases of our time, we must continue to wage war on the risks from earthquakes..."

The theory of plate tectonics, now only thirty years old, has revolutionized earth science, and for the first time explains the origin of earthquake stresses. But we are still far from understanding the magnitude and distribution of stresses in the crust, and the relationship between stress and earthquake potential. Recent studies relating static stress changes in past earthquakes to future earthquake potential may be the first step in this direction.

The concepts of *seismic moment* (which links earthquake rates to plate tectonic rates) and the *characteristic earthquake* (which relates the size of future earthquakes to the rupture lengths of past earthquakes) have found widespread use in seismic hazard analysis. Yet we still have a rather primitive understanding of how seismic moment is distributed among the many faults occurring along an active plate boundary, and the notion of *characteristic earthquake* seems to be losing ground to more complex models of fault rupture. Recent earthquakes such as Landers 1992 and Northridge 1994 are graphical reminders that the San Andreas is not the only game in town.

New technologies developed over the last decade now permit us to look at the earth in new ways. Broadband seismometers provide a detailed look at the earthquake source; the Global Positioning Satellite (GPS) system measures strain accumulating over wide regions of the earth's crust and relates it to earthquake potential; and portable digital seismic instruments allow detailed studies of fault zones and the geologic factors controlling strong ground motions from large earthquakes. Networks of all of these instruments are greatly enhancing our observational resolution, and shortening the time it takes to understand what happens during an earthquake.

"...we must strive to reach some common ground as to the nature of the earthquake problem..."

So while much has been learned over the last three to four decades, many questions remain and much is left to be done. The potential for fundamental breakthroughs in earthquake hazard assessment exist perhaps more now than ever before. That is why a strong and viable NEHRP is essential and why we must press forward with the basic scientific study of earthquakes. But at the same time, we must consider bold new approaches. The Southern California Earthquake Center embodies one new approach, where knowledge accumulated in fundamental research areas is integrated and distilled so that it can be transmitted to the general populous in a form useful for earthquake hazard mitigation. This requires a conscious effort to promote communication among researchers and between the producers and consumers of earthquake knowledge. It means sharing, rather than guarding, what each one knows.

And finally, while we must not shrink from reporting the natural diversity of opinion and uncertainty (which promotes further and deeper scientific study) in our science, we must strive to reach some common ground as to the nature of the earthquake problem at any given time. We must work toward consensus building, or perhaps more appropriately, "capturing the composite state of knowledge of an informed scientific community."* Doing so will benefit both society and the relevance of our science.

*C. Allin Cornell, Professor, Dept. of Civil Engineering, Stanford University; SCEC Master Model.

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LARSE *continued from Page 1 ...*

structural features originally targeted, including offshore faults, basement rocks beneath the Los Angeles basin, and deep crustal structure beneath the San Gabriel Mountains. Given the general high quality of the data, more refined analysis will likely resolve upper-crustal structures and additional deeper structures, so that we can begin to define the various crustal blocks that make up the tectonic framework of the Los Angeles region.

deployed along Line 1 with a minimum spacing through the San Gabriel Mountains of 1 kilometer. During four weeks of continuous monitoring, over 160 teleseisms and over 400 local events were recorded.

In 1994, LARSE continued with airgun and explosion experiments along three lines, including Line 1, crossing the Los Angeles region and the offshore Continental Borderland (LARSE94; Figure 1).

correspondence with numerous individuals and private groups. The public reception of this high-profile experiment was generally positive, owing in large part to the recent occurrences of the Northridge and other earthquakes in the area.

Seismograph deployment required access along numerous fenced drainage canals and through other publicly owned and privately owned facilities.

fired along multiple traverses of the offshore segments of the three lines. The airguns were recorded by a 4-kilometer streamer, 10 ocean-bottom seismographs, and 170 land seismographs. In the second phase of LARSE94 (Figure 1), explosions were detonated along the onshore segment of Line 1 and were recorded by a stationary array of 640 seismographs assembled from numerous institutions in North America. Through the

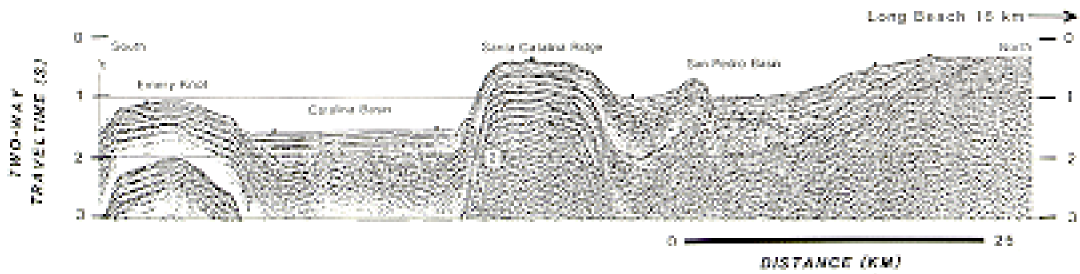

Figure 2. Constant-offset reflection section along the offshore part of Line 1 (Brocher et al., 1995). Ocean-bottom seismograph locations shown by black dots. Note differing sediment deformation between San Pedro and Catalina basins.

Experiment Design and Data Acquisition

LARSE began in 1993 (LARSE93) with a passive experiment along a line extending northeastward from Seal Beach across the Los Angeles basin and San Gabriel Mountains (Figure 1, Line 1). The objective of this experiment was to collect seismic-waveform data from local and teleseismic earthquakes to refine three-dimensional images of the lower crust and upper mantle in southern California, especially in the San Gabriel Mountains and across the San Andreas fault. During LARSE93, approximately 88 portable seismographs were

Onshore parts of Lines 2 and 3 are, respectively, Santa Monica northward through Northridge, and Redondo Beach eastward through the Los Angeles basin. Existing oil-industry seismic-reflection and well-log data will be used to determine the structure of the sedimentary basins along these three lines.

LARSE94 required unusual emphasis on several aspects of seismic data acquisition in the urban environment. The permitting process, which took two years, required not only an environmental assessment but addresses to city councils and other governmental bodies, extensive radio, television, and newspaper interviews, and

Security for the seismographs required, in many cases, complete burial of the recorder and batteries. Noise suppression required up to six passes along the offshore segments of the three lines with the airgun sources with a plan eventually to “stack” the data. It also required extensive pre-experiment noise measurements, avoidance of freeways, and detonation of explosions between the hours of 1:30 and 4:30 am. Care was taken to avoid damage from the explosions–both perceived and real.

During the first phase of LARSE94 (Figure 1), 20 airguns, towed by Lamont Doherty’s *R/V Ewing*, were

northern Los Angeles basin and San Gabriel Mountains, shots were spaced 1000 meters apart and the seismographs 100 meters apart in order to produce both a reflection and refraction image of the crust. North and south of this densely instrumented segment, seismographs and shots were spaced more widely to produce a wide-angle reflection and refraction image chiefly of the middle and lower parts of the crust.

The chief targets along offshore Line 1 were the Catalina, San Pedro basin, and Palos Verde Hills faults (Figure 1). The

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LARSE *continued from Page 4 ...*

chief targets along onshore Line 1 were the top of basement beneath the Los Angeles basin (never before imaged), the Elysian Park blind thrust fault system, believed to be the origin of the 1987 Whittier Narrows earthquake (M 5.9), the Sierra Madre fault system, believed to be the origin of the 1991 Sierra Madre earthquake (M 5.8), and the San Andreas fault. LARSE94 was designed to image these features using vertical-incidence and wide-angle reflections and also detailed velocity models, in which the faults might be evident as discontinuities or as tabular low-velocity zones. Sources and receivers were too sparse to obtain clear images of the Newport-Inglewood fault, origin of the 1933 Long Beach earthquake, or of the proposed Compton-Los Alamitos blind thrust fault in the southwestern Los Angeles basin.

Data quality obtained during LARSE94 was generally good. Airgun signals recorded by the streamer have excellent signal/noise ratios (SNRs) and show fine structural detail in constant-offset seismic-reflection sections (Figure 2). At onshore bedrock recording sites, airgun signals had good to moderate SNRs (≥ 1, Figure 3b), and at onshore sedimentary recording sites in the Los Angeles basin, moderate to poor SNRs (≤ 1). The airgun signals carried over 200 km, into the Mojave Desert. Ocean-bottom seismogram return was approximately 80%, and SNRs were commonly good to 70-kilometer offset. Data return for the land explosions was about 95%, and SNRs were generally excellent (Figures 3a, below; Figure 4, page 6).

Preliminary Crustal Images

Preliminary seismic images from Line 1 of LARSE94 are presented from south to north in Figures 2-4. A constant-offset reflection section along the offshore part of Line 1 (Figure 2) (consisting of data

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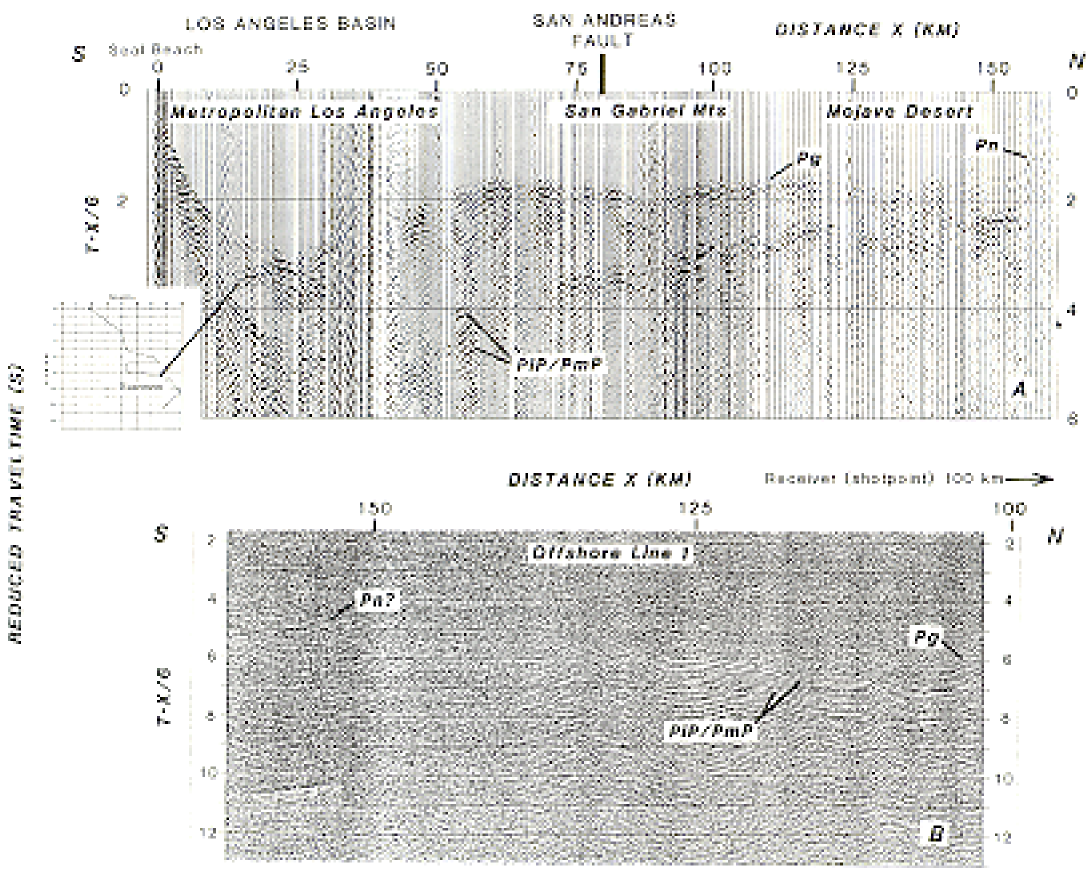

Figure 3a (above right). Record section for explosion at Shotpoint 9450 (Figure 1), at Seal Beach, reduced at 6 km/s. Clear signals recorded through metropolitan Los Angeles (ranges of 0-45 km) show strong reflection interpreted to be from basement beneath sedimentary and volcanic deposits of Los Angeles basin. Inset shows a 1-dimensional velocity model derived from this shot gather, indicating 8-km depth to basement. Also seen in record section are strong wide-angle reflections from the lower crust (PiP) and/or mantle (PmP) and mantle refractions (Pn).

Figure 3b (below right). Record section ("common-receiver gather") for airgun bursts along Line 1, recorded at a seismograph near Shotpoint 8260 (Figure 1), near the crest of the San Gabriel Mountains, reduced at 6 km/s. Strong PiP/PmP is seen. First arrival between about 120 and 160 km with the high apparent velocity is interpreted as Pn.

LARSE *continued from Page 5 ...*

recorded on the tenth channel of the streamer) shows folded, faulted, and erosionally truncated sedimentary rocks in San Pedro basin, but undisturbed sedimentary rocks to the south in the Catalina basin. Some of the multiple reflections apparent in this section will be suppressed when the multichannel data are sorted.

A record section from an explosion at Seal Beach (Figure 3a) shows excellent SNRs through much of metropolitan Los Angeles. Arrivals are delayed through the Los Angeles basin (ranges of 0-45 kilometers) and advanced in the San Gabriel Mountains (ranges of 45-85 kilometers). Importantly, a strong arrival at about 3.25 s reduced traveltime is interpreted as a reflection from the top of basement rocks beneath the sedimentary and volcanic rocks of the Los Angeles basin. Also evident in the section are reflections from the lower crust (PiP) and mantle (PmP) and refracted arrivals from the mantle (Pn).

A one-dimensional velocity model for the shallow structure near the Seal Beach shotpoint (Figure 3a inset) indicates approximately 8 kilometers of low- to intermediate-velocity (1.8-6.2 km/s) sedimentary and volcanic fill in the Los Angeles basin. Based on the strength of the basement reflection and the apparent velocity of the refraction associated with it, basement rocks may have a high seismic velocity (6.5-72. km/s), corresponding to gabbro or mafic metamorphic rocks. Similar one-dimensional models are obtained from reversing shots 30 kilometers northeast of Seal Beach, near the Whittier fault (see Figure 1).

A reversing record section of air-gun signals recorded near the crest of the San Gabriel Mountains (Figure 3b) shows strong reflections from the lower crust and/or mantle (PiP/PmP) and also refracted arrivals from the mantle. This remarkable record owes its clarity to the quiet bedrock recording location and to the fact that the airgun bursts were numerous (~one every 50 meters) and produced a coherent signal distinguishable through the noise.

Explosion record sections recorded near the crest of the San Gabriel Mountains indicate a prominent, subhorizontal reflective zone as shallow as 7.5 s (about 22 kilometers depth) (Figure 4). This reflective zone can be traced in preliminary stacked data throughout the San Gabriel Mountains, forming a gentle arch, with weaker reflectivity above it at the north and south margins of the San Gabriel Mountains and also weaker reflectivity beneath it (to 12 s) in the north-central San Gabriel Mountains. The Moho is inferred from independent earthquake tomographic data to be at a depth of about 30 kilometers (or about 10 s) beneath the San Gabriel Mountains. Wide-angle reflections from the 7.5 s reflective zone and/or Moho are interpreted in Figure 3a. This reflective zone, interpreted to lie chiefly or entirely in the lower crust, may or may not represent a decollement; however, it almost certainly represents an important change of physical properties, or a "block" boundary, within the crust.

Data are currently being processed for release as U.S. Geological Survey Open-File Reports. Most should be released before the end of the year.

Gary S. Fuis
Thomas M. Brocher
James Mori
Rufus D. Catchings
Uri S. ten Brink
Kim D. Klitgord
Robert G. Bohannon
US Geological Survey

David A. Okaya
Thomas L. Henyey
USC/SCEC

Robert W. Clayton
Caltech

Paul M. Davis
Mark L. Benthien
UCLA

Trond Rybert
GeoForschungsZentrum

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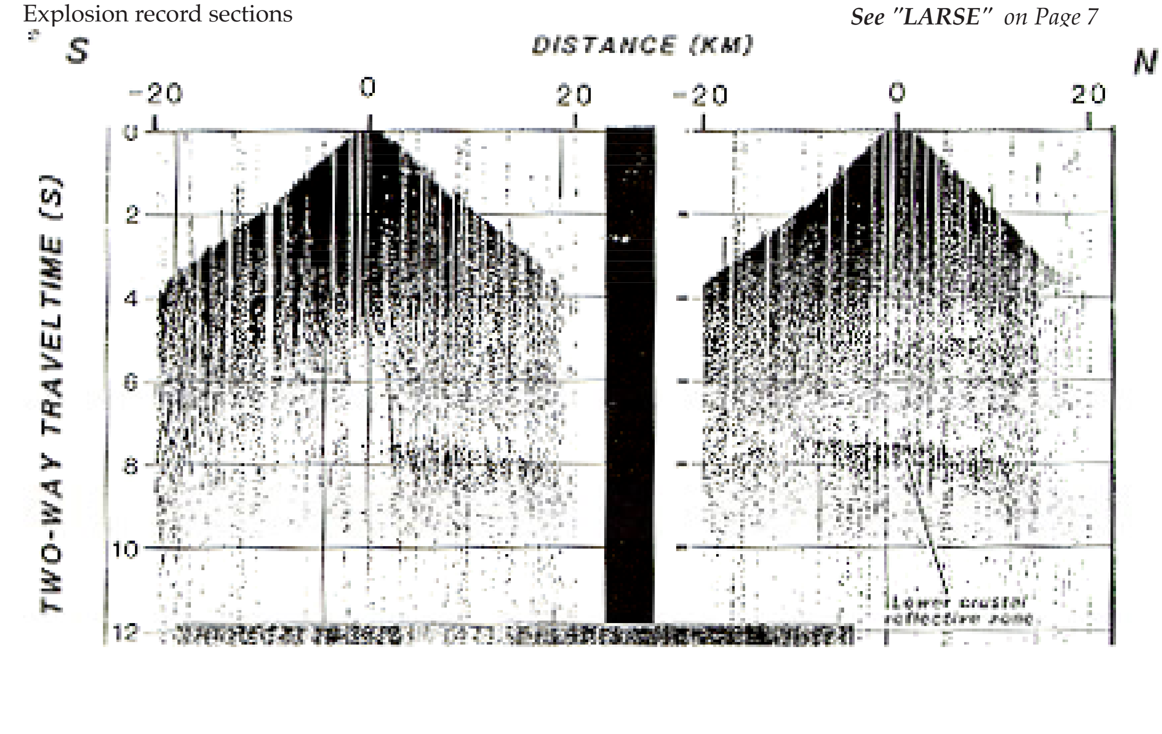

Figure 4 (right). Record sections for explosions at Shotpoints 8220 and 8260 (Figure 1), near crest of San Gabriel Montains. No reducing velocity; corrected only for spherical divergence. Strong reflector at 7.5 s is interpreted as lower-curstal feature (about 22 km deep). Reflector can be traced as gentle arch throughout San Gabriel Mountains.

LARSE ***continued from Page 6 ...***

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Gary S. Fuis, et al.

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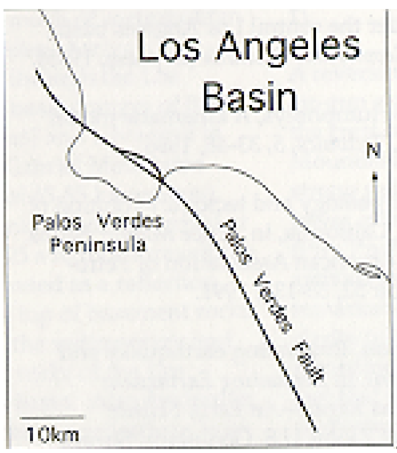
Quarter Fault

Each Issue of the SCEC Newsletter will feature a southern California fault. In this issue, we feature...

The Palos Verdes Fault

The Palos Verdes Fault angles northwest under the Vincent Thomas Bridge toward the giant dinosaur cranes. →



Much of nature is fractal. Capillaries, arteries and veins branch out in a similar fashion at different scales. Stream tributaries are often smaller versions of the river they're feeding. Fractures and faults in a region will also sometimes repeat their geometries. The Palos Verdes Fault, for example, is a scaled down version of the mother of all of southern California's faults: the San Andreas. Where the dextral San Andreas fault is moving roughly 30 mm per year in Southern California., the dextral Palos Verdes fault runs at roughly 3 mm per year. Where the San Andreas is 1000 km long, the Palos Verdes fault is approximately 100 km long. The San Andreas has a "big bend" where the Transverse Ranges are being squeezed up. The Palos Verdes fault has a "little bend" where the peninsula is being squeezed up by 0.04 mm/yr. The "Pelona Schist" is exposed at outcrops along the big bend in the San Andreas. The Catalina Schist, its southwestern equivalent, is exposed at the little bend in the Palos Verdes Fault.

And what a pretty sight all that uplifted schist and sediment is: with its houses and gardens spilling down ancient wave cut terraces, the Palos Verdes peninsula rises out of our L.A. megalopolis still looking like the channel island it was only few hundred thousand years ago. Often misty and mysterious, with peacocks wailing and the nightly patter of furry four footed beasts scampering across rooftops and down gullies, Palos Verdes doesn't so much call to mind San Francisco, with which it is sometimes compared, but a story-book Hobbit-land.

It is currently thought an earthquake as large as a M_L 7.2 could occur if the entire trace of the P.V. fault ruptured, which could prove to be most unfortunate as it runs through L.A. harbor,

See "PV Fault" on Page 9

Insurance Industry Workshop Proceedings and Audio Tapes Available

In our next issue, we will review the November 9-10 SCEC Insurance Industry Workshop results. Printed proceedings will be available free of charge to participants of the workshop, and can be obtained by others (release date and cost to be determined) through SCEC.

Audio tapes are available immediately. To order, contact SCEC's Knowledge Transfer office (see below).

All tapes are fully guaranteed for exchange or refund. 1-Tape Sets (one tape per Workshop Session) are $4. Tapes may be ordered separately, or complete sets (12 tapes) may be ordered for $45 total. Shipping charges are not included.

Contact:

SCEC Knowledge Transfer
University of Southern California
Mail Code 0742
Los Angeles, CA 90089-0742
phone 213/740-1560
e-mail: *ScecInfo@usc.edu*

PV Fault *continued from Page 8 ...*

under an oil refinery and other heavily developed areas. Recent seismic reflection experiments suggest the onshore fault splays out into strands in a band as wide as 1.5 km near Gaffey Street with most recent activity occurring in the northeastern strands.

Probably the most stimulating area to travel cross the fault—the trace of which has been almost completely obscured by development—is where it angles northwest directly between the two support structures of the Vincent Thomas bridge. Its always thought-provoking to consider the lay of the fault while driving over the crest of the bridge and gazing at L.A. harbor, its cargo, cranes, oil tankers, coal mountains, the oil refineries and their flame capped exclamation points and beyond. It's a long way down.

Michael R. Forrest

FEMA's First Biennial National Mitigation Conference: "Partnerships for Building Safer Communities" December 6-8, 1995

Topics discussed will include risk assessment, measuring mitigation success, building codes and enforcement, the latest research, GIS/GPS, pre- and post-disaster mitigation, floods, wind/hurricanes, earthquake hazards, all hazards insurance, public awareness and involvement, retrofitting, legislative updates, and more.

Who should attend this conference? Anyone who has a stake in mitigation, community development, or disaster planning and recovery, and understands the need to strengthen existing relationships and develop new partnerships to reduce our Nation's hazard vulverability.

For more information: Call the Federal Emergency Management Agency at (800) 769-3861.

Earthquake Map Now Available from the U.S. Geological Survey

"Earthquakes in California and Nevada" depicts the epicenters of 300,000 earthquakes, including 49 of magnitude 6.5 or larger that have occurred in the two-state area since 1836.

The map offers a ready reference for areas that have had few if any earthquakes during the past 160 years. California's great central valley, for instance, has only a few dots depicting earthquake epicenters.

The map, priced at $12 for a paper copy or $22 for a laminated copy, including shipping costs, is available by mail only from:

Earthquake Maps
U.S. Geological Survey
Box 25046, Federal Center, MS 967
Denver, CO 80225

Orders must include the name and number of the map "Earthquakes in California and Nevada; Open-File Report 94-647", and a check or money order, payable to DOI/USGS.

SCEC Annual Meeting: Glimpses

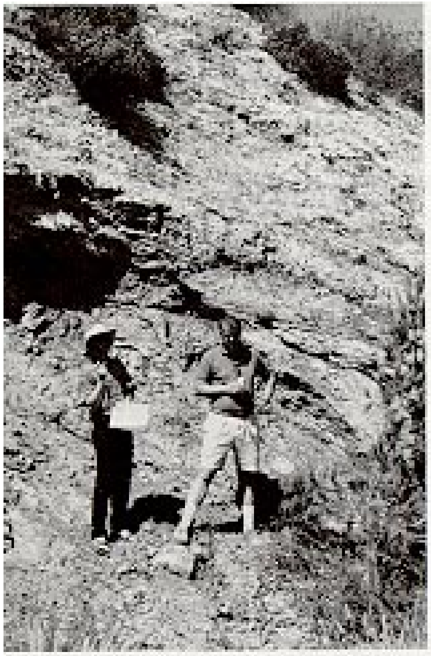
The 1995 SCEC Annual Meeting was held at the Ojai Valley Inn in Ojai, California, September 17 -19, 1995. Welcome remarks from SCEC Executive Director Tom Henyey were followed by statements from Jim Whitcomb (NSF) and John Sims (USGS). Participants heard special presentations on the progress of the Phase III Report (Norm Abrahamson); Status of the GPS Initiative (Duncan Agnew); Results of LARSE (Rob Clayton); New Seismic Network Initiative (Egill Hauksson); Status of Northridge Investigations (Jim Mori); and the SCEC Research Utilization Council (Jill Andrews).

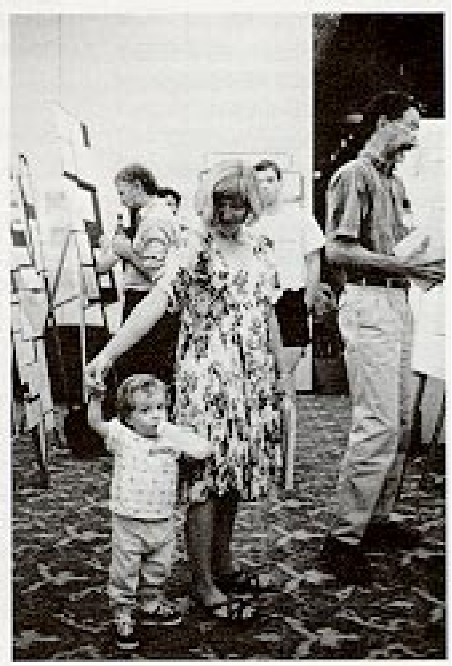
Summary Reports from Group Leaders were presented by Kei Aki, Steve Day, Kerry Sieh, Rob Clayton, Duncan Agnew, Egill Hauksson, and Leon Knopoff.

Three invited talks were given before the working group meetings. Jim Rice and Yehuda Ben-Zion presented "Rupture Dynamics, Slip Patterns and Event Populations in Earthquake Fault Models;" Lynn Sykes and Jishu Deng presented "Evolution of the Stress Field in Southern California During the Past 200 Years and Implications for Long-Term Earthquake Prediction;" and Ruth Harris, Ross Stein, and Robert Simpson presented "Earthquake Stress Triggering and Relaxation Shadows - An Explanation for the Pattern of Southern California Earthquakes from 1858-1995."

Future newsletters will cover more news from the meeting, and in the meantime, we picked out a few of our favorite moments to share them with our readers here.

Jill Andrews





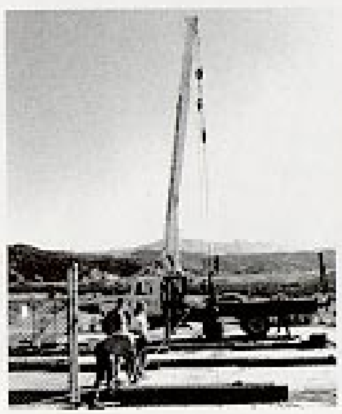
Feature: visit with a SCEC scientist

A Visit with Rachel Abercrombie

Intoxicating and wonderful as life is, it's often easy to forget that roses have thorns—that pain and unpleasantness are sometimes crouching round the next corner, ready to spring. Like the pain of having to say that sad and ugly word, "Goodbye," to favored friends, colleagues and mentors.

Two departures are particularly unpleasant this fall. First, Professor Kei Aki will be spending half of each year on La Reunion Island. And now, regrettably, it's time to say goodbye to Rachel Abercrombie, whose dry British wit, insight, and inspiring industry will be missed by the many collaborators, loyal cohorts and friends she's accumulated during her tenure as a SCEC researcher. (We'll most miss the staccato "WOT?" she uttered, when presented with a thought or plot of dubious scientific merit.)

Abercrombie has been a SCEC researcher since November of 1991, when she arrived from England through the SCEC Visitor's Program. "One intent of the visitor's program is to identify young scientists from other countries that would not be considering potential opportunities for earthquake research in Southern California," says Tom Henyey of the program. "A good example the success of this program was the Center's ability to attract Abercrombie to Southern California and her subsequent research on microearthquakes using borehole instruments."



Center: Rachel Abercrombie poses for the camera in front of the USC Science Building.

Upper right: USC's Periklis Beltas and David Adams help seal the Cajon Pass borehole.

Lower right: A hammer and a pick and a dynamite stick--off to work!

Lower left: Retrieving the sonde from the borehole.

Upper left: Derek Manov, carrying the down-hole instrument he helped develop.

Peter Leary was Abercrombie's SCEC sponsor scientist at that time and he, with Derek Manov, had installed the first borehole seismometer in the Cajon Pass Scientific drill hole in August 1991. This instrument recorded the mainshocks and aftershocks of the 1992 Joshua Tree, Landers and Big Bear earthquake sequences. In November of 1993, Abercrombie replaced the seismometer with two instruments at 1.5 and 3 km depth. The 3 km seismometer was the deepest seismometer in all of North America.

Rachel used the borehole seismicity data to determine that constant stress drop scaling holds from about M_L 0 to M_L 7 and that the Gutenberg-Richter b-value is constant above M_L 0.5 in the Cajon pass region. Leary and Abercrombie calculated the intrinsic and scattering attenuation in the upper crust, and Abercrombie also found, "There is indeed some seismicity on the locked segment of the San Andreas."

See "Abercrombie" on Page 13

Abercrombie *continued from Page 12 ...*

Rachel worked with Jim Brune at the University Nevada, Reno, for four months in 1994, further studying earthquake parameters and showing the that Gutenberg-Richter relation holds down to about M_L 0. "I definitely enjoyed working with her," says Brune about Abercrombie. "On our microearthquake paper she was willing to spend hours counting tiny microearthquakes, cheerfully! Some say that she gave the best seminar that they had ever heard. She certainly doesn't take anyone's word for anything important unless she understands it clearly (even if they are world famous!)."

Abercrombie also worked closely with Jim Mori (USGS Pasadena) during her stay. "The first time I saw Rachel was when she came to Caltech. She was jaywalking across Wilson Avenue, right in front of a motorcycle cop," recalls Mori. "When she stopped to wave at the Pasadena policeman, I thought, 'This person is not from around here.' Clearly she wasn't from around here, but since that time I've had the pleasure to work with her and learned that southern California has gained from the energy and enthusiasm she has brought to the work at the Cajon Pass and on earthquake source parameters." By closely examining the emergent onset of the Landers 1992 event on seismogram recordings, Abercrombie and Mori determined the quake was actually a compound event. A M_w 4.4 followed by a M_w 5.6 "detonated" the M_w 7.3 main shock.

Having collected enough borehole data since 1991 to (in Rachel's words) "keep scientists busy for years," and with her September departure imminent, Abercrombie went to retrieve the seismometers from the Cajon Pass borehole one early Saturday last July. (See photos opposite page.)

"When you've been out there every two weeks for three years....actually, I'm HOPING it's the last time I have to go out there!" she joked. Vandals, unfortunately, sometimes made Abercrombie's visits to download borehole data and change batteries less than delightful. She lost one REFTEK, four batteries, one GPS unit, numerous padlocks, a transformer, and drilling tubing. Cables were cut, and vandals even stole a fiberglass T-hut. "But nobody took the sensors, they're still down in the hole. No one's stolen them!" said Abercrombie.

Though pulling the titanium "sondes" out of the two boreholes at Cajon Pass required less effort than putting them in, the operation kept the oil crew from Tiger Wireline and a group of USC geophysics graduate students sharp and alert. The two cables carrying the seismometers weighed 1500 pounds each and Periklis Beltas (USC) was good enough to tell everyone the tale of how he had seen a ship cable snap on a dock in Greece and literally cut a man in half.

"One intent of the visitor's program is to identify young scientists from other countries that would not be considering potential opportunities for earthquake research in Southern California..."

The stress was quickly dissipated with a laugh fest, however, which was orchestrated by Abercrombie's husband (computer virtuoso Phil). He told the assembled about some of her work at UCLA with Paul Davis, where she has been involved with designing and testing seismometers for future deployment on Mars. Phil and company gleefully imagined what it might be like to be a Martian, walking the canals, on a balmy Martian afternoon, only to find metal missile airborne seismometers raining out of the sky, and dropping "THUNK!" around your feet, kicking up clouds of red dust.

Much as Rachel has loved living in pink, brown and lovely Los Angeles and navigating morning traffic on the 405 and 110 freeways, she's now going to a permanent position with the Institute of Geological and Nuclear Sciences in green and unpopulous Wellington New Zealand. "I'm looking forward to working on some new problems. For example, the seismotectonics of the Hikurangi Margin, and deep earthquake sources. Also, if there happens to be a borehole available..."

Abercrombie will still be active in SCEC research, however. "I hope to keep close links with SCEC. I will continue working with two graduate students at USC who are working on SCEC related projects. I've really enjoyed working in California. The ground has hardly stopped moving since I arrived! I'm very grateful to SCEC for the opportunity. The monthly meetings especially enabled me to meet and get to know scientists from all over California and Nevada. I've had some excellent opportunities for collaborative work, especially with Jim Brune and Jim Mori. I've also made many friends with whom, thanks to e-mail, I can stay in touch."*

Michael R. Forrest

*Rachel's new e-mail address is: *R.Abercrombie@gns.cri.nz*

SCEC Scientists' Publications, Fall 1995

The complete SCEC scientists' publications listing is updated and available on a continuous basis. Please contact the SCEC Administrative Office, 213/740-5843, to obtain updated listings. Selected publications may be available through the Center; however, to obtain authorized copies of preprints or reprints, please contact the authors directly. The Spring quarterly newsletter includes all publications; subsequent issues will include newly submitted papers only.

216. Leary, P. C., "Quantifying Crustal Fracture Heterogeneity by Seismic Scattering," *Geophysical Journal International*, 122, pp. 125-142, January, 1995.

217. Leary, P. C., "The Cause of Frequency-Dependent Seismic Absorption in Crustal Rock," *Geophysical Journal International*, 122, pp. 143-151, January, 1995.

218. Sieh, K., "The Repetition of Large Earthquake-Ruptures," *Proceedings of the National Academy of Sciences*, submitted August 1995.

219. Kagan, Y. Y., Comment on "The Gutenberg-Richter or Characteristic Earthquake Distribution, "Which is it?" by S. G. Wesnousky, *Bulletin of the Seismological Society of America*, submitted 1995.

220. Olsen, Kim B., R. Archuleta, "3-D Simulation of Earthquakes on the Los Angeles Fault System," *Bulletin of the Seismological Society of America*, submitted August 1995.

221. Field, Edward H., S.E. Hough, "The Variability of PSV Response Spectra Across a Dense Array Deployed During the Northridge Aftershock Sequence," *Earthquake Spectra*, submitted September 1995.

222. McGill, Sally; Grant, Lisa B., "Summary of Findings: Workshop on Preparing a Digital Fault and Fold Map and Database for Southern California," report prepared for the Southern California Earthquake Center, August 29, 1995.

223. Knopoff, L. (title forthcoming).

224. Anderson, John G., Y. Lee, Y. Zeng, S. Day, "Control of Strong Motion by the Upper 30 Meters, *Bulletin of the Seismological Society of America*, submitted August 1995.

225. Huftile, G. J., and Yeats, R. S., 1996, "Deformation Rates Across the Placerita (Northridge Mw=6.7 aftershock zone) and Hopper Canyon Segments of the Western Transverse Ranges Deformation Belt," *Bulletin of the Seismological Society of America*, Northridge earthquake volume, in press, 1995.

226. Hauksson, Egill, K. Hutton, H. Kanamori, L. Jones, "Preliminary Report on the 1995 Ridgecrest Earthquake Sequence in Eastern California, *Seismological Research Letters*, submitted October 1995.

227. Field, Edward H., "Spectral Amplification in a Sediment-Filled Valley Exhibiting Clear Basin-Edge Induced Waves", *Bulletin of the Seismological Society of America*, submitted October 1995. ♦

Putting Down Roots in Earthquake Country: Order While They Last!

If you live in southern California, you can get your free copy of the layman's version of the "Seismic Hazards in Southern California–Probable Earthquakes, 1994-2024" at your local library. Organizations (both profit and non-profit) can arrange for large quantities through the Southern California Earthquake Center by calling the phone number below.

The 32-page, full-color handbook, authored by seismologist Lucile M. Jones of the U.S. Geological Survey, explains the risks southern Californians face from earthquakes–and what can be done about it.

Call 213/740-1560 and order now while supplies last!

Seismic Hazards Report Now Available

Reprints of Seismic Hazards in Southern California: "Probable Earthquakes, 1994 - 2024," published in the April edition of the *Bulletin of the Seismological Society of America*, is available through the SCEC Administrative Offices. Copies, which include color figures and maps, are $5 each.

Contact:
SCEC Knowledge Transfer
University of Southern California
Mail Code 0742
University Park
Los Angeles, CA 90089-0742
phone 213/740-5843
fax 213/740-0011
e-mail: ScecInfo@usc.edu

SCEC Research Activities

Research on the Hollywood Fault

Most Recent Surface Rupture on the "Ozzie and Harriet" Trench

James Dolan (University of Southern California), Thomas Rockwell (San Diego State University), and Donovan Stevens (California Institute of Technology) drilled a North-South transect of nine adjacent boreholes just west of down-town Hollywood during the late summer, 1995. Immediate results showed that the most recent surface rupture on the Hollywood fault occurred during latest Pleistocene to early or mid-Holocene time. Details of the borehole data are available from principal author James Dolan.

Preliminary Conclusions

The present long quiescent interval (between ~5,000 and 15,000 years), implies that the Hollywood fault ruptures during very infrequent, and therefore possibly very large, earthquakes. The authors speculate that the Hollywood fault may rupture either with other faults in the 215 kilometer-long Raymond-Hollywood-Santa Monica-Malibu Coast-Santa Cruz Island-Santa Rosa Island fault system and/or with the Santa Monica Mountains blind thrust fault or shallower blind thrust faults to the south. Alternatively, very infrequent Hollywood fault earthquakes may reflect slip rates of <<1 millimeter per year.

See "Hollywood" on Page 16

Right: Donovan Stevens, free as Peter Pan, after he is raised out of the trench.

Below: Tri-Valley Drilling excavating a trench across the Hollywood Fault, directly in front of the "Ozzie and Harriet" house.

Hollywood *continued from Page 15 ...*

Soil stability and logistical problems dictated the use of the borehole technique, as a conventional trench, such as the trench highlighted on the cover of the summer 1995 issue of the SCEC Quarterly newsletter, began to collapse as soon as excavation had begun. The boreholes were placed adjacent to one another by drilling and logging one hole, backfilling with concrete, and drilling the adjacent hole after the concrete had hardened. Using this method, they achieved complete exposure of the fault zone. Although this method was much slower and more expensive than conventional trenching, it allowed them to collect the data in safety at a site that would not support a conventional trench. In addition, the adjacent-borehole technique provided exposures down to >13 meters depth, much greater than the 5 to 6 meters depth of exposure provided by conventional trenches. This method proved to be critical at this site, which lies on an alluvial fan where rapid sediment accumulation has deeply buried evidence of past earthquakes.

Many may ask why this trench is called the "Ozzie and Harriet," although some may have by now guessed that the site is located on the property once used by the television industry in producing the famous "Ozzie and Harriet" show.

For more information:

James F. Dolan
University of Southern California
Department of Earth Sciences
Los Angeles, CA 90089

Above: Shoring specialist, James Dolan, Thomas Rockwell, excavator, Donovan Stevens, and SDSU's Kim Thorup.

Below: Kim Thorup, Thomas Rockwell (crouching), James Dolan, excavator.

Southern California Integrated GPS Network

Several SCEC organizations are in the process of expanding continuous Global Positioning System (GPS) station coverage in southern California. GPS is used to monitor deformation of the earth's crust and can measure the slow, quiet movement between earthquakes as well as large sudden displacements due to earthquakes. Continuous GPS networks, such as the southern California Permanent Geodetic GPS Array (PGGA), were first implemented to provide a framework for GPS surveys that were conducted relatively infrequently to measure the interseismic velocity field. The PGGA proved useful, however, for both the Landers and Northridge earthquakes.

Following the Northridge earthquake NASA, the United States Geological Survey (USGS), and the National Science Foundation (NSF) committed funds to expand the Los Angeles area network from two to 25 stations. SCEC organizations involved in the oversight and implementation of the network include the Jet Propulsion Laboratory, Massachusetts Institute of Technology, Scripps Institution of Oceanography, University of California, Los Angeles, and the United States Geological Survey (USGS). The new stations and PGGA are part of the Southern California Integrated GPS Network (SCIGN). NASA has committed $1M for 25 stations to be added to the network in 1996 and addtional funds are being sought from NASA, NSF, the USGS, and other agencies to expand the network to 250 stations over the next few years. SCEC hosted a workshop in March of 1995 to design the network and outline the major science goals of the project. A report of the workshop can be obtained by anonymous FTP from *sideshow.jpl.nasa.gov in /pub/SCEC.*

The network will be used to study the pervasive fault system in southern California, including blind thrust faults. The primary goals of the network are to: 1) Measure the interseismic velocity field to 1 mm/yr over a period of five years and measure the strain distribution across the region. 2) Test geologic models and estimate the fraction of strain accumulation that is released through earthquakes. 3) Improve our understanding of fault and earthquake mechanics to provide better estimates of seismic hazard in the region.

Relevant GPS World Wide Web pages:

Southern California Earthquake Center
http://www.usc.edu/dept/earth/quake/index.html
Jet Propulsion Laboratory
http://milhouse.jpl.nasa.gov
Scripps Institution of Oceanography
http://jon.ucsd.edu
University of California Los Angeles
http://scec.ess.ucla.edu/uclagps.html
United States Geological Survey
http://tango.gps.caltech.edu/hudnut/cont-gps.html

Andrea Donnellan

Natural Hazards Seminar Series Schedule

The Jet Propulsion Laboratory invites you to attend the following presentations, which are part of a series on natural hazards studies:

Wednesday, December 6, 1995 (double header), 2 pm
- Frank Webb, Observations at Mammoth Mountain using GPS
- Vince Realmuto, Multispectral Imaging of Volcanic Sulphur Dioxide

Thursday, January 4, 1996, 2 pm
- Paul Lundgren, Finite Element Modelling and Earthquakes in Costa Rica
- Gilles Peltzer, Radar Interferometry and Tectonics of China

Thursday, May 2, 1996, 2 pm
- Andrea Donnellan, GPS Results from the Northridge Earthquake

IMPORTANT INFO FOR VISITORS:
The Jet Propulsion Laboratory (JPL) is located in northwestern Pasadena at 4800 Oak Grove Dr. Exit the 210 freeway Berkshire/Oak Grove Drive." Turn east upon exiting the freeway and make a left turn at Oak Grove Drive (T intersection with Berkshire). Continue up Oak Grove 1/2 mi. to the lab. Park in the visitor's lot and go to Visitor Control. Tell them you are here for the seminar, and ask for directions to building 180, room 101. Allow extra time to clear visitor control. JPL is a NASA facility operated by Caltech. NON-US CITIZENS wishing to attend please alert Ron Blom for obtaining permission to enter the Lab. JPL is a US government facility and entry permission for citizens of some countries must be obtained in advance.

For More Information Contact:

Ronald G. Blom, Ph.D.
Lead Scientist, Terrestrial Sciences Research Element
Jet Propulsion Laboratory, Mail Stop 183-501
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109-8099 USA
Internet: Ronald.G.Blom@jpl.nasa.gov
Telephone 1-818-354-4681
Fax 1-818-354-0966

SCEC Global Science Classroom Activities

SCEC Summer Internship Initiative, 1995, Part 2

SCEC funded 11 students in its second year of supporting undergraduate research. As the program was designed to encourage women and underrepresented minorities to continue their academic careers and later, enter a professional career related to earthquake science, SCEC made progress in achieving a balance by sponsoring projects for six women and five men. In 1994, nine men and four women were supported. In addition to the students' day-to-day research experiences in the lab and field, many participated in a three-day Technical Orientation staged in the Owens Valley in California's Sierra Nevada region. Students studied geological features of the area, explored evidence of past earthquakes and volcanoes and completed a geologic mapping activity.

In the late summer, SCEC was invited to sponsor a student (or students) to the NSF Conference on Diversity in the Scientific and Technical Workforce, September 21-23. Mandy Johnson, an Asian American intern, was selected to represent SCEC. She presented a poster, *The California Earthquake Catalog for earthquakes with any magnitude greater than or equal to 5.5 between the years 1769 and 1994*, and served as a Geosciences Roundtable panelist to discuss strategies to increase the participation of underrepresented groups in the geosciences.

The program also welcomed the repeat of Rachel Abercrombie and Lisa Grant as outstanding role models and mentors for the students they supervised. Both had participated in the program in 1994 as Research Advisors. Listed below are the summer interns, their institutions, their research advisors and some of the project titles submitted at the completion of the internship. SCEC wishes to thank all university faculty and research advisors for their support of the students and the program!

Curt Abdouch
Director
SCEC Education

I=Intern; *In*=Institution; *R*=Research Advisor(s); *P*=Research Project

I	Windy Brimer
In	UC Santa Barbara
RA	Marc Kammerling
P	*Seismic Hazards in the Santa Barbara Channel Using High Resolution Seismic Reflection Data and Dated Horizons from ODP 893*
I	Andrew Byers
In	UC Santa Barbara
RA	Jamie Steidl, Ralph Archuleta
P	*Site-Specific Strong-motion Amplification Factors for the Southern California Region*
I	Heather Hodgetts
In	University of Southern California
RA	Rachel Abercrombie
P	*Microseismicity in the Vicinity of the Cajon Pass Borehole*
I	Mandy Johnson
In	University of Southern California
RA	David Jackson, UCLA
P	*The California Earthquake Catalog for Earthquakes with any Magnitude Greater Than or Equal to 5.5 between the Years 1769 and 1994*
I	Jason McKenna
In	UC Santa Barbara
RA	*Fabian Bonilla, Jamie Steidl, Ralph Archuleta*
I	Susannah Pazdral
In	Wellesley College
RA	Mark Legg, ACTA, Inc.
P	*Mapping the Thirtymile Bank Detachment Fault*
I	Ryan Smith
In	University of Southern California
RA	Michelle Robertson
P	*In Situ Calibration of the Mainland LABNET Geophones*
I	Donovan Stevens
In	California Institute of Technology
RA	James Dolan, USC
I	Carmen von Stein
In	Central Washiington University
RA	Lisa Grant, Woodward-Clyde Consultants
I	Mike Watkins
In	UC Santa Barbara
RA	Kim Bak Olsen
I	Isabelle Wicks
In	University of Southern California
RA	Charles Sammis
P	*Observation of Log-Period Activity in the Regional Seismicity Before and After the May 2, 1983 M=6 Coalinga Earthquake*

SCEC Global Science Classroom Activities

Seismic Sleuths National Leadership Institute

The 1995 *Seismic Sleuths* National Leadership Institute was conducted Monday, July 17 to Friday, July 21, 1995. Twenty-four people participated in the Institute, which was held at the National Emergency Training Center in Emmitsburg, Maryland. Support for the training course was provided by FEMA. Participants' backgrounds ranged from secondary classroom teachers to emergency management personnel to museum educational staff, and nationally recognized earthquake research and educational experts. SCEC summoned an experienced team of educational specialists and scientists to serve as facilitators for the Institute.

The stated objectives of this Institute were:

- To acquaint participants with Seismic Sleuths earthquake education materials for secondary grades 7-12.
- To acquaint participants with key earthquake science and seismic safety concepts
- To provide practice in developing National Standards-related instructional plans using Seismic Sleuths
- To demonstrate the use of Seismic Sleuths as being revised and aligned with the new National Earth Science Educational Standards
- To provide practice in conducting Seismic Sleuths activities
- To model the role of Instructors as teaching/learning facilitators, as recommended by the National Science Education Standards
- To provide opportunities for participants to assemble an earthquake engineering lab model
- To acquaint participants with educational resources from FEMA and other sources

Throughout the workshop, scheduled activities and instructional strategies such as field trips, activity demonstrations, practice sessions, videofests and "make and take" opportunities assured that all of the above were met.

Summer VINE Program: A Successful Experiment in Neighborhood Science Education and Ethnic Diversity

About 1,000 elementary students learned about the natural and built environment (including geology and earthquake science and safety) in this neighborhood environmental education pilot program. Loosely modeled after the VINE Network, it is an inner city environmental education program managed by the North American Association for Environmental Education.

The program guided students through *Tremor Troop* elementary earthquake education activities each week of the program. With the help of 13 Science Activity Leaders, these high school students represented African American, Hispanic American and Asian American ethnic groups. The six-week program was conducted in South Central inner city Los Angeles Boys and Girls Club and USC neighborhood school sites. The program was supported by a combination of funding from the Southern California Academy of Sciences, Chevron Oil Company, ARCO, FEMA, the City of Los Angeles Summer Youth Employment and Training Program and the USC Neighborhood Outreach Program. The program also supported four earth science graduate students as worksite supervisors and employed an African American elementary teacher as program coordinator.

The second phase—the development of a small-scale enterprise— may link students to opportunities in earthquake safety kit design, manufacture and distribution.

For more information:
Curt Abdouch
Director, SCEC Education

Seismic Sleuths Review Panel: The SCEC Global Classroom on the National Scene

SCEC's experience and success in training teachers led to the award of a supplemental grant from FEMA to conduct an independent review of *Seismic Sleuths* and the development and field testing of a model for a training workshop to be used throughout the nation as well as at additional FEMA training institutes.

Perhaps the most significant activity related to educational materials and services for secondary teachers to date has been the review of the *Seismic Sleuths* materials. The review was conducted in response to feedback received from the field that the materials needed some revision before being published in final form. SCEC convened a six-member panel in March, 1995 to carry out this mandate. Preliminary and final reports were submitted to FEMA. The panel also considered the elements, processes and general daily agenda for a three-day and four-day model training workshop. The model was scheduled to be tested in April, but it was mutually agreed that it would be used as the format for the 1995 National Leadership Institute, to be held in Emmitsburg, Maryland, July 17-21.

The panel's most fundamental and potentially far-reaching recommendation was to align *Seismic Sleuths* with the new National Earth Science Education Standards.

Southern California Seismic Network: Special Report

The 1995 Ridgecrest Earthquake Sequence in Eastern California

The Ridgecrest earthquake sequence began on 17 August 1995 with a M_L5.4 earthquake. As of October 3, 1995, the Southern California Seismic Network (SCSN) had recorded over 4500 events in the sequence, with eight events of M≥4.0. These earthquakes are occurring along the eastern edge of the Indian Wells Valley along a small stretch of the thoroughgoing Eastern California Shear Zone (ECSZ). Previous large events within the ECSZ include the 1992 (M_W7.3) Landers earthquake sequence and the 1872 (M7.6) Owens Valley earthquake. The only large earthquake to occur near Indian Wells Valley, was the 1946 Walker Pass (M6.0) earthquake on an unknown fault in the Sierra Nevada mountains to the west. The ECSZ transfers some of the relative motion between the north America and Pacific Plates away from the San Andreas fault to the western Great Basin of the Basin and Range province.

The Indian Wells Valley is flanked by the Coso Range to the north, the Argus Range to the east and the Sierra Nevada to the west. The valley floor is cross cut by a northerly-trending mosaic of fault segments that merge towards the north with the frontal fault of the Sierra Nevada or the rupture zone of the 1872 earthquake. In the south, this mosaic of segments diffuses into a broad zone of faulting that disappears before it is cut off by the west-striking Garlock fault. The mosaic of fault segments consists of north to northwest striking, as well as a lesser number of north-east-striking faults, most of short length, of less than a kilometer up to 10 km length (Figure 1, page 21).

During the last three decades the seismicity of this region has been characterized by swarms of earthquakes, some of which have lasted more than 12 months. These swarms typically have thousands of small earthquakes and the largest earthquakes in the magnitude range of 4 to 5. The swarms tend to migrate in space. For instance, the fourteen-months-long swarm in 1980-1981 migrated from north to south over a distance of 12 km, with temporal bursts in activity. The largest earthquake to occur in the valley itself was a M_L4.9 event in April 1982. It caused some ground cracking (Roquemore and Zellmer, 1983) on two short fault segments.

The M_L5.4 Earthquake of 17 August 1995

The M_L5.4 Ridgecrest earthquake that occurred on 17 August 1995 was located 11 miles north of Ridgecrest, on the county boundary between Kern and San Bernardino Counties. The focal depth of this event was shallow, or 6 km deep, as is common in this region. This event was felt widely in southern California. The first motion focal mechanism of the M_L5.4 earthquake had a dominantly normal-faulting mechanism (Figure 2, page 22). The focal mechanism derived from regional surface waves, however, showed a more dominant strike-slip component (H. K. Thio, written communication, 1995). This difference in the focal mechanism derived from the two independent data sets suggests that the event may have begun with normal faulting and quickly evolved into right-lateral strike-slip faulting.

The SCSN station coverage in the region is good with about 10 km average station spacing. To obtain accurate hypocenters we inverted arrival time data from 250 earthquakes in this sequence for an improved velocity model and a set of corresponding station delays. We used the VELEST program (Kissling et al., 1994). The final locations were calculated using HYPOINVERSE (Klein, 1985) and focal mechanisms were determined from first motion polarities using FPFIT (Reasenberg and Oppenheimer, 1985).

In the next 5 weeks the M_L5.4 earthquake was followed by over 2,500 aftershocks, 3 of which were M_L>4 aftershocks. The first of these larger aftershocks occurred on the same day while the two later ones occurred on August 29 and September 11. The spatial

See "Ridgecrest" on Page 21

Earthquake Faults in Southern California

The most recent source of information about faults in California is the *Fault Activity Map of California*. Copies may be obtained by mailing a check in the amount of $20, which covers the map and shipping, with your written request for Map #GDM-006, to:

California Division of Mines and Geology
PO Box 2980
Sacramento, CA 95812-2980

Ridgecrest *continued from Page 20 ...*

distribution of the immediate aftershocks suggests that the M_L5.4 earthquake occurred on a north-northwest-striking fault. The two later M_L>4 aftershocks occurred to the northeast of the mainshock and were followed by events forming a northeast lineation, suggesting that they activated a separate northeast-striking fault (Figure 2). In addition, a vertical north-striking group of aftershocks to the southwest of the mainshock hypocenter suggests that three separate faults might be involved in this part of the sequence (Figure 2).

The M_L5.8 Earthquake of 20 September 1995

The M_L5.8 earthquake occurred about 2 km to the south-southeast of the epicenter of the M_L5.4 earthquake at a focal depth of 5 km. It had a strike-slip focal mechanism with a north-northwest striking nodal plane, aligned with the strike of the aftershock distribution. The aftershocks form a 7-km-long distribution that defines an almost vertical plane in the depth range of 3 to 11 km (Figure 3). The strike of this distribution coincides with that of the M_L5.4 event so the M_L5.8 mainshock may be occurring on a southeastward extension of the M_L5.4 earthquake's fault.

Over 1,900 aftershocks have been recorded in the two weeks since the M_L5.8 mainshock. The largest was a M_L4.9 event on September 24. This event had a focal mechanism significantly different from the other events, with left-lateral strike-slip faulting on a north-striking plane (Figure 3, page 24). This mechanism and the location of the event, six km to the northeast of the main part of the sequence, suggests that a fourth fault was activated in this event.

This sequence has shown significant temporal variability in its distribution in time, space, and magnitude. The locations of the sequence events have migrated with time, extending from the original aftershock zone to both the northeast and southeast. Each of the larger events (M>4) has been accompanied by a burst of smaller earthquakes, but the M3 aftershocks have also shown a notable temporal clustering. This clustering has lead to a significant variability in the b-

See "Ridgecrest" on Page 22

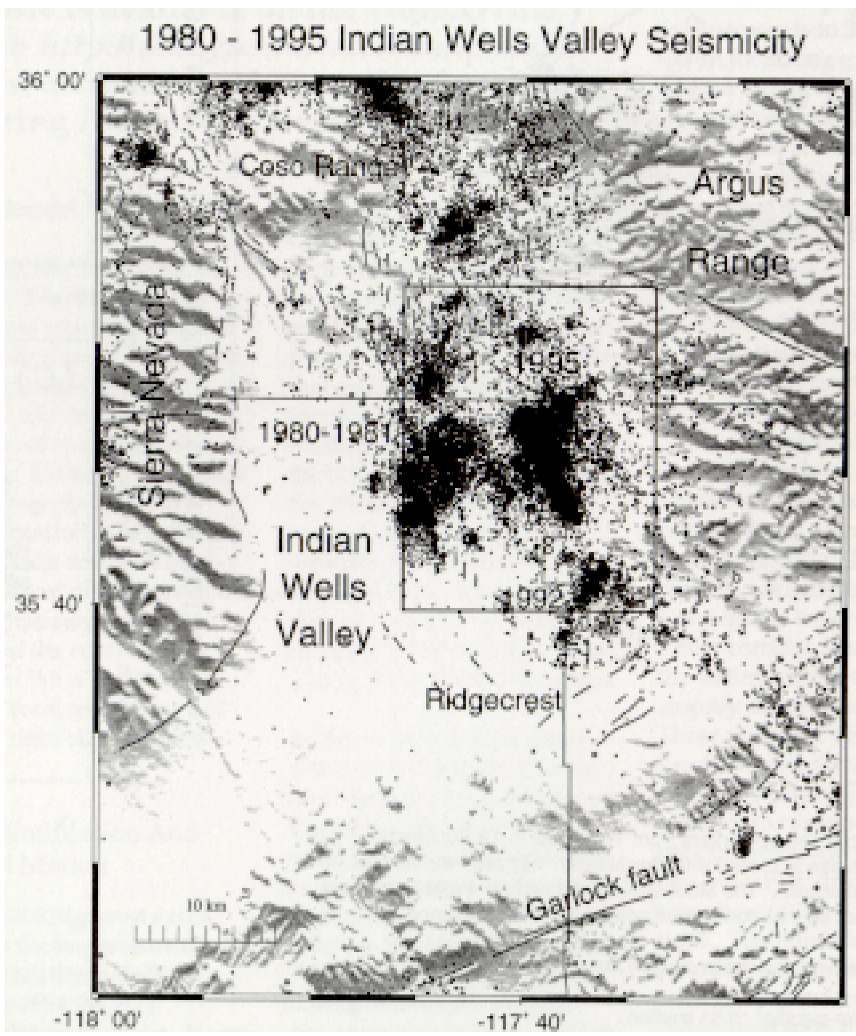


Figure 1. Overview of seismicity in Indian Wells Valley recorded by the Southern California Seismic Network from 1980 to 1995. Symbol size is scaled with magnitude. The swarms of 1980-1981, 1992, and the 1995 sequence are labeled with the year. The box indicates the location of Figures 2 and 3. The straight lines are the county boundaries.

Ridgecrest *continued from Page 21 ...*

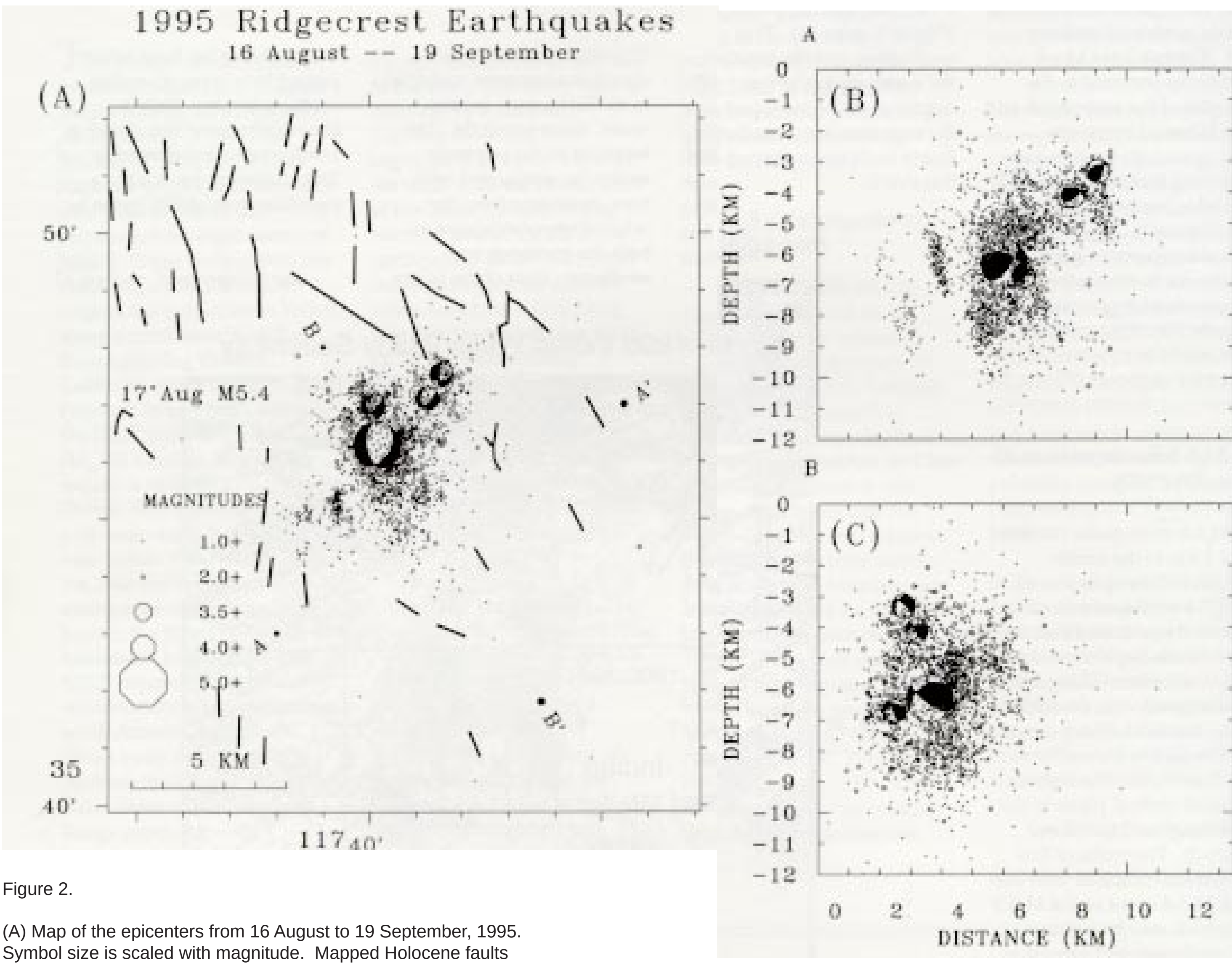


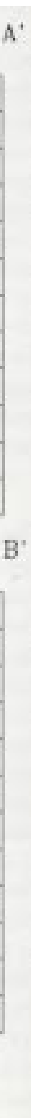
Figure 2.

(A) Map of the epicenters from 16 August to 19 September, 1995. Symbol size is scaled with magnitude. Mapped Holocene faults are also shown. The M5.4 earthquake and M>4 aftershocks are indicated by their lower hemisphere focal mechanisms.

(B) Strike-normal cross section and

(C) strike-parallel cross section.

Ridgecrest *continued from Page 22 ...*



value of the sequence with time. The original aftershocks to the M_L5.4 event had a moderately high b-value of 1.13 ± 0.07. In the first day of aftershocks to the M_L5.8, the b-value went down to 0.90 ± 0.08 (the average for Californian aftershocks), but since then it has returned to a higher value (1.10±.10).

Geological Field Investigations

The Ridgecrest earthquakes may have caused triggered slip on fault segments within the Airport Lake fault zone (Roquemore and Zellmer, 1986), outside of the epicentral and aftershock areas. A short (3km), northsouth striking fault segment, located approximately 3 km to the northwest of the epicentral region experienced surface cracking possibly related to surface rupture in both the August 17 and September 20 events.

The epicentral region of the August 17 and September 20, 1995 Ridgecrest earthquakes was investigated for potential surface rupture. Following the August 17 event a highly fragmented line of surface cracking was located along a mapped fault segment within the Airport Lake fault zone. The Airport Lake fault zone is a broad zone of northsouth striking normal and oblique slip fault segments. The cracks were generally 1 to 2 meters long and separated by several meters over a total length of less than 1 km. Two parallel cracks separated by about 50 cm formed along some of the segments. Other segments showed en echelon patterns. Close inspection of the cracking revealed evidence of up to 2 mm of right-slip as observed in pebbles pulled away their matrix on the opposite side of the cracks. The areas closest to the epicenter and areas to the east where the fault plane (determined from seismicity) would project to the surface was also investigated but only randomly oriented cracks interpreted to be caused by shaking and settlement was observed.

"Earthquake information from the SCSN is available on the World Wide Web *http://scec.gps.caltech.edu/*...[and was] accessed by thousands of users during August and September."

Following the September 20, 1995, M5.8 earthquake, the region was again investigated for surface rupture. The same fault segment within the Airport Lake fault zone experienced more extensive cracking. Evidence for surface rupture was observed in several locations along the preexisting fault scarp. A maximum vertical displacement of 1 cm was measured near the middle of the rupture zone. Also near the middle of the rupture zone, a maximum of 8mm of right-slip was measured.

Rapid Notification And Ground Motion

The M_L5.8 Ridgecrest earthquake is the largest earthquake to strike southern California since the 1994 (M_w6.7) Northridge earthquake. It was widely felt over southern California, even though its location, in the desert 150 kilometers north of Los Angeles, meant that damage was confined to Ridgecrest and its vicinity. The Caltech US Geological Survey Broadcast of Earthquakes (CUBE) reported the location and preliminary magnitude of both mainshocks within 3 minutes of their occurrence. This information was used by local utilities and transportation companies to determine the scope of their deployment of field crews following the earthquake. The CUBE system broadcasts earthquake information automatically via commercial paging to both belt pagers and pagers connected to computers that can display on a map the location and magnitude. Earthquake information from the SCSN that is available on the World Wide Web (http://scec.gps.caltech.edu/), including near-real time locations and magnitudes and the weekly bulletin, were accessed by thousands of users during August and September.

In the last few years, Caltech and the US Geological Survey have been working to improve the capability of the SCSN to provide quick estimates of the location of strong shaking to emergency management officials. Eighteen broad-band TERRAscope stations, eight analog SCSN stations with strong motion sensors, and ten new strong motion sensors, deployed as part of the Automated Monitoring of Strong Ground Motions Project (AMOES) and located at sites of the Pacific Bell Company are now operating in southern California. These stations provide near-real time estimates of strong ground shaking. The data are transmitted from the remote sites using frame relay digital technology under a California Research and Educational Foundation (CalREN) grant from Pacific Bell.

The M_L5.8 earthquake provided the first test of the new enhancements to SCSN and CUBE for strong ground motion monitoring. Contours of measured peak horizontal and vertical accelerations are shown in Figure 4. Presumably the ground shaking was highest at the epicenter and decreased rapidly with distance. Because of the sparse distribution of high-dynamic range stations in eastern California the contours of ground motion are not exactly centered on the epicenter. Instead large peak values caused by local site amplification effect the pattern of ground motions. The contours that are well constrained in the Los Angeles to San Bernardino urban corridor also show how the sedimentary basins locally amplify the ground shaking. These new data demonstrate that emerging technologies now are becoming available to enhance the capabilities of regional networks to process and quickly distribute information about ground accelerations. The reliability of the information, however will be strongly dependent on adequate station distribution.

See "Ridgecrest" on Page 24

Ridgecrest *continued from Page 23 ...*

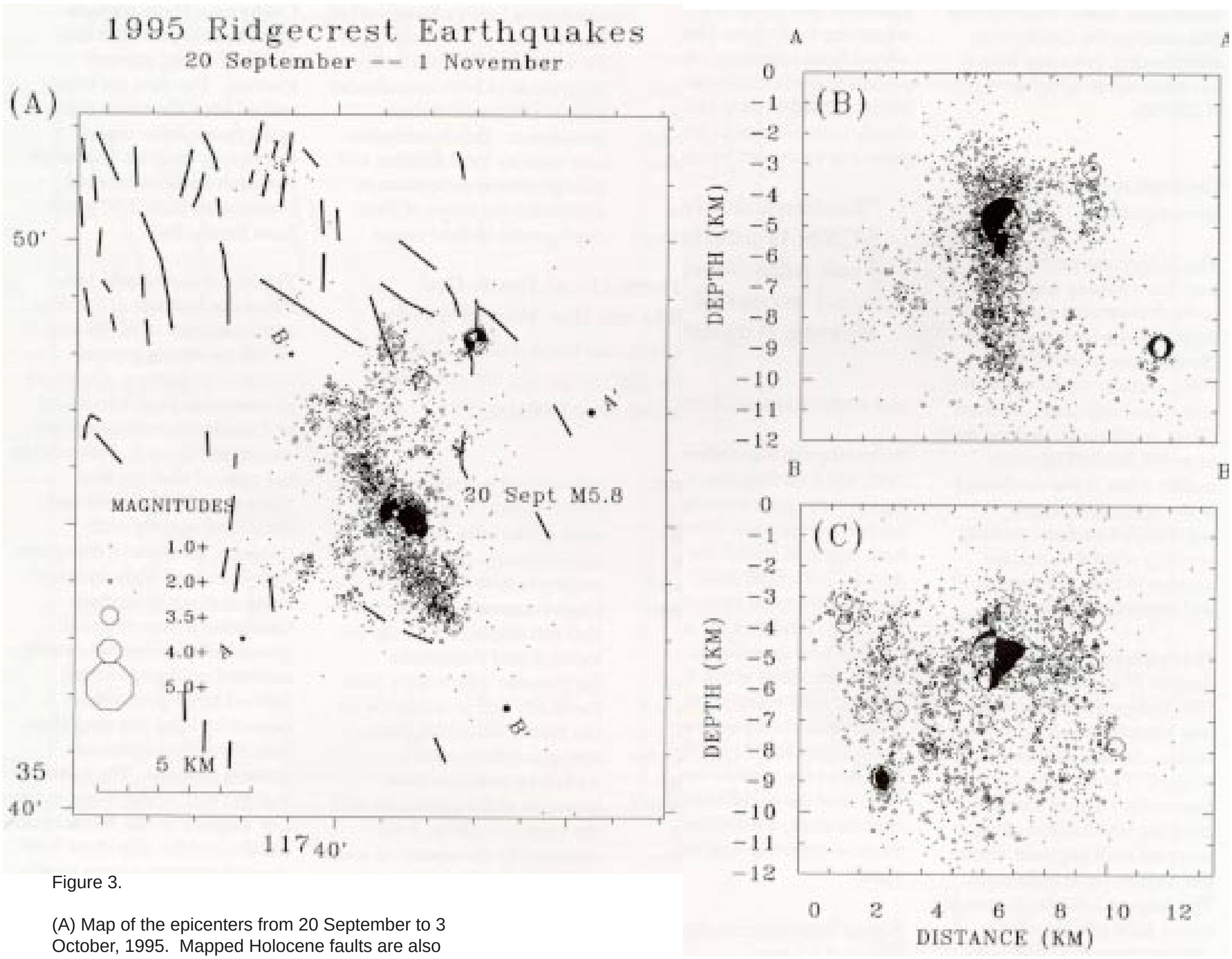


Figure 3.

(A) Map of the epicenters from 20 September to 3 October, 1995. Mapped Holocene faults are also shown. The M5.8 earthquake and M>=4 aftershocks are indicated by their lower hemisphere focal mechanisms.

(B) Strike-normal cross section and

(C) strike-parallel cross section.

Ridgecrest *continued from Page 24 ...*

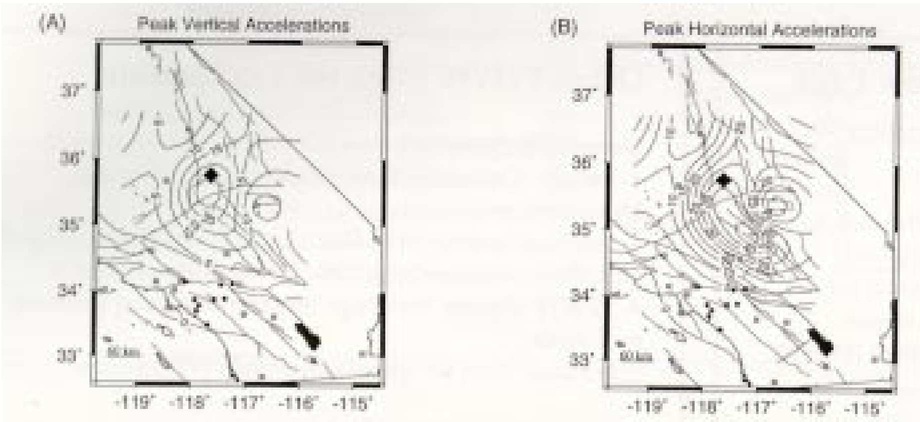


Figure 4. (A) Vertical and (B) horizontal peak accelerations in cm/sec[2] from the M5.8 earthquake (epicenter indicated by solid diamond). The ground motions are affected by distance from the epicenter and local site effects. The open squares are TERRAscope stations while the filled circles are analog SCSN stations and digital AMOES/CalREN stations with strong motion sensors.

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Discussion

The most notable feature of the 1995 Ridgecrest sequence is the multiple faults involved in the sequence and the spatial migration of the aftershocks with time. This spatial migration has been characteristic of previous swarms in the general region (1981-1992 Indian Wells Valley, 1983 Durrwood, 1990 (Jones and Dollar, 1986)), but these mainshocks were smaller than those in the 1995 sequence. The only other recent, large, southern Californian earthquake with similarly migrating aftershocks was the 1992 M6.1 Joshua Tree earthquake. That event was also in the ECSZ and was a preshock to the M_w7.3 Landers earthquake (Hauksson, et al., 1993).

Although the M_L5.8 Ridgecrest earthquake is the largest recorded in this region, earthquakes of larger magnitude are possible.

Egill Hauksson
Kate Hutton
Hiroo Kanamori
Seismological Laboratory
Caltech

Lucile Jones
James Mori
Susan Hough
USGS

Glenn Roquemore
Irvine Valley College

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SCEC WWW URL

http://www.usc.edu/dept/earth/quake

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"What is SCEC?"--a summary of the Center's history and purpose, including a description of the Master Model concept.
"Formal Mission"--Mission statement and list of Working Groups and Leaders, with links to more detailed descriptions of the research conducted by each of the groups.
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Jill Andrews

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http://www.yahoo.com
- Internet Search (via Netscape Corporation)
http://home.netscape.com/home/internet-search.html
- WWW Viewer Test Page (ensure that your browser will work)
http://www-dsed.llnl.gov/documents/WWWtest.html

Earthquakes and Seismology

- Yahoo - Earthquakes section
http://www.yahoo.com/Environment_and_Nature/Disasters/Earthquakes
- Seismo-surfing the Internet
http://www.geophys.washington.edu/seismosurfing.html
- USGS - Menlo Park (Earthquake info, past and current)
http://quake.wr.usgs.gov/ or *http://info.er.usgs.gov/*
- Recent Quakes (with a great map viewer)
http://www.civeng.carleton.ca/cgi-bin/quakes
- Kobe shaking (color photo of shaking intensity)
http://quake.wr.usgs.gov/QUAKES/shake/kobe/kobeshake.html

Engineering and Preparedness

- NCEER (National Center for Earthquake Engineering Research)
http://nceer.eng.buffalo.edu/
- Earthquake Engineering Research Center (EERC)
http://nisee.ce.berkeley.edu/
- Structural Engineers Association of California
http://www.power.net/users/seaoc-ad/
- Earthquake Hazard Maps (ABAG Searchable maps)
http://www.abag.ca.gov/bayarea/eqmaps/eqmaps.html
- Emergency Preparedness Info Exchange
http://hoshi.cic.sfu.ca/~anderson
- Federal Emergency Management Agency (FEMA)
http://www.fema.gov
- California Office of Emergency Services
http://www.oes.ca.gov/8001
- Other Civil Engineering Servers
http://www.civeng.carleton.ca/Other-Civil.html

Peter Clark and Katie Frohmberg
UC Berkeley
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November 1995

9 -10 SCEC-sponsored Insurance Industry Workshop. Proceedings and audio tapes from the work shop will be available through the Knowledge Transfer office. Call 213/740-1560.

13 -15 National Science Foundation Science and Technology Centers Administrators and Directors meeting, Washington, DC.

15 Presentation by SCEC Executive Director and Knowledge Transfer Director to the Seismic Safety Commission, briefing on the Insurance Industry Workshop, San Jose, CA.

20 SCEC Steering Committee Meeting, USC SCEC Conference Room.

December 1995

6-8 FEMA's First Biennial National Mitigation Conference, Washington, DC. See advertisement, page 9.

11-15 American Geophysical Union annual meeting, San Francisco, CA.

January 1996

20 Association of Engineering Geologists, Shortcourse on the SCEC Phase II Report, Davidson Conference Center, USC. For more information, contact SCEC Knowledge Transfer office, 213/740-3459.

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Contributing Writers:
Curt Abdouch, SCEC
Keiiti Aki, USC/SCEC
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