SCEC Southern California Earthquake Center

Southern California Earthquake Center

1996 Annual Meeting

October 20-22, 1996

Riviera Resort and Racquet Club
Palm Springs, California

Telephone (213) 740-5843 FAX (213) 740-0011

Southern California Earthquake Center

Southern California Earthquake Center

1996 Annual Meeting

October 20-22, 1996

Riviera Resort and Racquet Club
Palm Springs, California

Telephone (213) 740-5843 FAX (213) 740-0011

Table of Contents

1996 SCEC ANNUAL MEETING AGENDA

Saturday, October 19

1:00 p.m. **Steering Committee Meeting**

Sunday, October 20

9:00 a.m. **Field Trip led by Kerry Sieh**

7:00 p.m. **Icebreaker and Dinner in Honor of Keiiti Aki**

9:00 p.m. **Poster Session (Posters remain available until Tuesday morning)**

9:30 p.m. **Advisory Council Meeting**

Monday, October 21

8:00 a.m. **Session I: Plenary Session**

Welcome and Introduction	Henyey
SCEC Science Program Overview	Jackson
Report on Earthquake Response	Mori
Report of SCEC Workshops	Jackson, Andrews

Invited Talks

Ross Stein (USGS, Menlo Park): Divining the Earthquake Source from Seismology, Paleoseismology, and Geodesy

Jim Dieterich (USGS, Menlo Park): Time Dependent Earthquake Probabilities

Tom Heaton (Caltech): The Role of Dynamic Friction in Earthquake Ruptures

Paul Somerville (Woodward-Clyde, Pasadena): Path and Site Effects on Strong Motion in Los Angeles: Insights from Northridge"

Lunch @ 12:30 p.m.

Session II: Working Group Meetings

1:30 to 3:00 p.m.	Education and Outreach	Abdouch Andrews
3:00 to 4:30 p.m.	Group A:	Jackson
4:30 to 6:00 p.m.	Groups B and H:	Day Martin

Dinner at 6:00 p.m.

Dinner Speaker: Tom Jordan (MIT): Is the Study of Earthquakes a Basic Science?

8:00 p.m.	SCIGN Meeting	Prescott

Tuesday, October 22

8:00 to 9:30 a.m.	Groups C and G:	Sieh Knopoff
9:30 to 11:00 a.m.	Groups D and F:	Clayton Hauksson
11:00 to 12:30 p.m.	Group E	Hudnut

<u>End of SCEC Meeting</u>

Lunch @ 12:00 p.m. for SCEC Advisory Council and Steering Committee Advisory Council meets in Executive Session after lunch.

1996 SCEC ANNUAL MEETING PARTICIPANTS

Curt Abdouch	USC
Mark Abinante	UCLA
Abrahamson, Norm	Consultant
Kei Aki	USC
Greg Anderson	UC-San Diego
John Anderson	Nevada-Reno
Jill Andrews	USC
Ralph Archuleta	UC-Santa Barbara
Don Argus	JPL
Abu M. Asad	Nevada-Reno
Luciana Astiz	UCSD
Matt Bachman	Caltech
Eli Baker	UC-San Diego
Yehuda Ben-Zion	Harvard
Mark Benthien	USC
Jacobo Bielak	Carnegie-Mellon
Tom Bjorklund	Houston
Ann Blythe	USC
Yehuda Bock	UC-San Diego
Fabian Bonilla	UC-Santa Barbara
David Bowman	USC
Sergio Chavez-Perez	Nevada-Reno
James Chin	USC
Hung-Chie Chiu	USC
Rosemary Claire	Palos Verdes School District
Rob Clayton	Caltech
Lloyd Cluff	PGE
Cheryl Contopulos	Caltech
Allin Cornell	Stanford
C.B. Crouse	Dames and Moore
Debbie Dauger	Caltech
Jim Davis	CDMG
Marcy Davis	SCEC Summer Intern UC-Santa Barbara
Paul Davis	UC-Los Angeles
Thom Davis	Davis & Namson
Phil Dawson	USGS-Menlo Park
Steve Day	San Diego State
Jim Dieterich	USGS-Menlo Park
Jim Dolan	USC
Danan Dong	JPL

Andrea Donnellan	JPL
Macon Doroudian	UCLA
Ernie Duebendorfer	Northern Arizona
Ned Field	USC/Lamont
Mike Forrest	USC
Bill Foxall	LLNL
Tom Fumal	USGS-Menlo Park
John Galetzka	Caltech
Shang-xing Gao	UC-Los Angeles
Eldon Gath	Leighton & Associates
Peter Geiser	CogniSeis Development
Maggi Glasscoe	SCEC Summer Intern
	USC
Michael Gurnis	Caltech
Larry Gurrola	UC-Santa Barbara
Katrin Hafner	Caltech
Jeanne Hardebeck	Caltech
Ruth Harris	USGS-Menlo Park
Ross Hartleb	UC-Santa Barbara
Egill Hauksson	Caltech
Suzanne Hecker	USGS-Menlo Park
Tom Heaton	Caltech
Mike Heflin	JPL
Don Helmberger	Caltech
Tom Henyey	USC
Susan Hough	USGS-Pasadena
Ken Hudnut	USGS-Pasadena
Gary Huftile	Oregon State
Gene Humphreys	Oregon
Ken Hurst	JPL
Larry Hutchings	LLNL
Dave Jackson	UC-Los Angeles
Anshu Jin	USC
Hadley Johnson	UC-San Diego
Mandy Johnson	SCEC Summer Intern/USC
Lucy Jones	USGS-Pasadena
Tom Jordan	MIT
Yan Kagan	UC-Los Angeles
Marc Kamerling	UC-Santa Barbara
Ed Keller	UC-Santa Barbara
Katherine Kendrick	USGS-Menlo Park
Bob King	MIT
Nancy King	USGS-Menlo Park

Leon Knopoff	UC-Los Angeles
Monica Kohler	UC-Los Angeles
Hermann Lebit	USC
Matthew Lee	UC-Los Angeles
Mark Legg	ACTA
Cheng-Peng Li	USC
Yong-gang Li	USC
Scott Lindvall	Harza Engineering
Hong Liu	UC-Los Angeles
John Louie	Nevada-Reno
Catalina Luneburg	USC
Bruce Luyendyk	UC-Santa Barbara
Greg Lyzenga	Harvey Mudd
Harold Magistrale	San Diego State
Mehrdad Mahdyiar	Vortex Rock Consultants
Aaron Martin	UC-Santa Barbara
Geoff Martin	USC
John Marquis	Caltech
Shirley Mattingly	FEMA
Simon McClusky	MIT
Sally McGill	Cal State-San Bernardino
Keith McLaughlin	Maxwell Labs
John McRaney	USC
Dennis Mileti	Colorado
Bernard Minster	UC-San Diego
Jim Mori	USGS-Pasadena
Karl Mueller	Colorado
Gretchen Mullendore	SCEC Summer Intern UC-Santa Barbara
Mark Murray	Stanford
Xian-xi Ni	UC-Los Angeles
Craig Nicholson	UC-Santa Barbara
Stefan Nielsen	UC-Los Angeles
Robert Nigbor	Agbabian Associates
Julie Norris	Caltech
David Oglesby	UC-Santa Barbara
David Okaya	USC
Kim Olsen	UC-Santa Barbara
Mike Oskin	Caltech
Steve Park	UC-Riverside
Mark Petersen	CDMG
John Pfanner	San Diego State
Dan Ponti	USGS-Menlo Park

David Potter	UCLA
Vince Quitoriano	Caltech
Will Prescott	USGS-Menlo Park
Donna Rathman	SCEC Summer Intern Irvine Valley College
Mike Reichle	CDMG
Robin Reichlin	NSF
Jim Rice	Harvard
Keith Richards-Dinger	UC-San Diego
Tom Rockwell	San Diego State
Peter Rodgers	UC-Santa Barbara
Barbara Romanowicz	UC-Berkeley
Charlie Rubin	Central Washington
John Rundle	Colorado
Chandan Saikia	Woodward-Clyde
Charlie Sammis	USC
Anja Schlosser	USC
Craig Scrivner	Caltech
Nano Seeber	Lamont-Doherty
Paul Segall	Stanford
Bruce Shaw	Lamont-Doherty
Kaye Shedlock	USGS-Denver
Zheng-kang Shen	UC-Los Angeles
Kerry Sieh	Caltech
John Sims	USGS-Reston
Roger Slayman	UC-Santa Barbara
Bob Smith	Utah
Paul Somerville	Woodward-Clyde
Jim Spotila	Caltech
Jamie Steidl	UC-Santa Barbara
Ross Stein	USGS-Menlo Park
Mark Stirling	Nevada-Reno
Lynn Sykes	Lamont-Doherty
Cheryl Tateishi	CA Office of Emergency Services
Mary Templeton	Cal State-Fullerton
Leon Teng	USC
Maria Todorovska	USC
Susan Tubessing	EERI
Jeni Tucker	SCEC Summer Intern Cal State-San Bernardino
Allan Tucker	SCEC Summer Intern USC
Alexei Tumarkin	UC-Santa Barbara

Alla Tumarkina	UC-Santa Barbara
David Valentine	UC-Santa Barbara
Mladen Vucetic	UCLA
Dave Wald	USGS-Pasadena
Chris Walls	San Diego State
Steve Ward	UC-Santa Cruz
Steve Wesnousky	Nevada-Reno
Jim Whitcomb	NSF
Nadya Williams	UC-San Diego
Frank Wyatt	UC-San Diego
Bob Yeats	Oregon State
Doug Yule	Caltech
Yuehua Zeng	Nevada-Reno
Hua-wei Zhou	Houston

SCEC ORGANIZATION - 1996

Management

Center Director:	Thomas L. Henyey University of Southern California
Science Director:	David D. Jackson University of California, Los Angeles
Director for Administration:	John K. McRaney University of Southern California
Director for Education:	Curtis D. Abdouch University of Southern California
Director for Knowledge Transfer:	Jill H. Andrews University of Southern California
Outreach Specialist:	Mark Benthien University of Southern California
Sr. Technical Secretary:	Susan I. Turnbow University of Southern California

Board of Directors

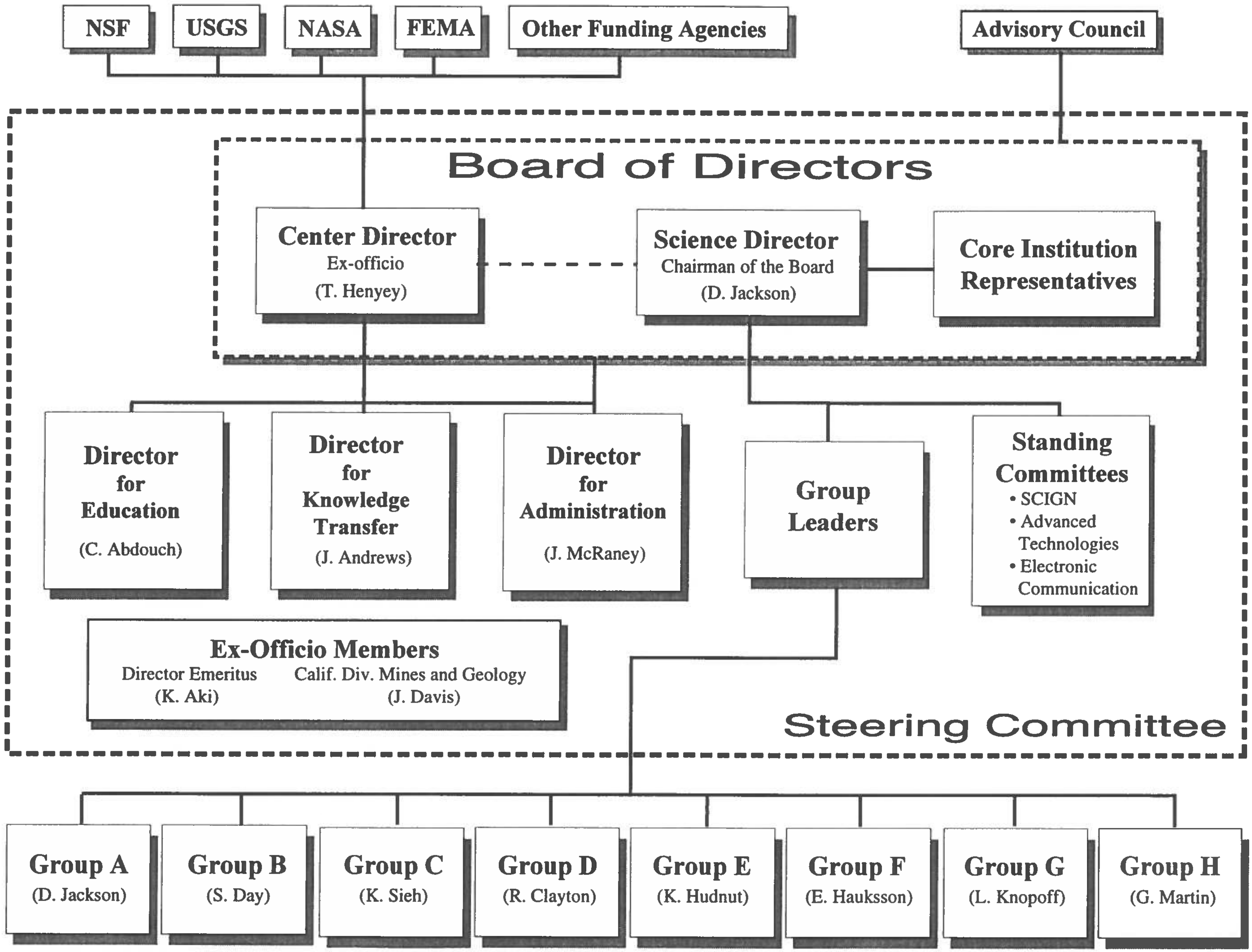
Chair:	David Jackson University of California, Los Angeles
Vice-Chair:	Bernard Minster University of California, San Diego
Members:	Ralph Archuleta University of California, Santa Barbara
	Robert Clayton California Institute of Technology
	James Mori United States Geological Survey
	Charles G. Sammis University of Southern California
	Leonardo Seeber Columbia University
Ex-officio:	Thomas Henyey University of Southern California

Research Group Leaders

A: Master Model:	David D. Jackson University of California, Los Angeles
B: Strong Motion Prediction:	Steve Day San Diego State University
C: Earthquake Geology:	Kerry Sieh California Institute of Technology
D: Subsurface Imaging and Tectonics:	Robert Clayton California Institute of Technology
E: Crustal Deformation:	Kenneth Hudnut United States Geological Survey
F: Seismicity and Source Parameters:	Egill Hauksson California Institute of Technology
G: Earthquake Source Physics:	Leon Knopoff University of California, Los Angeles
H: Engineering Applications:	Geoffrey Martin University of Southern California

Steering Committee Members (ex-officio)

Director Emeritus	Keiiti Aki University of Southern California
State of California Representative	James Davis California State Geologist
SCIGN Board Chairman	Will Prescott United States Geological Survey


NSF
USGS
NASA
FEMA
Other Funding Agencies
Advisory Council
Board of Directors
Center Director
Ex-officio
(T. Henyey)
Science Director
Chairman of the Board
(D. Jackson)
Core Institution Representatives
Director for Education
(C. Abdouch)
Director for Knowledge Transfer
(J. Andrews)
Director for Administration
(J. McRaney)
Group Leaders
Standing Committees
• SCIGN
• Advanced Technologies
• Electronic Communication
Ex-Officio Members
Director Emeritus
(K. Aki)
Calif. Div. Mines and Geology
(J. Davis)
Steering Committee
Group A
(D. Jackson)
Group B
(S. Day)
Group C
(K. Sieh)
Group D
(R. Clayton)
Group E
(K. Hudnut)
Group F
(E. Hauksson)
Group G
(L. Knopoff)
Group H
(G. Martin)

1996 SCEC ADVISORY COUNCIL

Robert SMITH (Chair), University of Utah, Department of Geology and Geophysics, Salt Lake City, UT 84112-1183

Lloyd S. CLUFF, Pacific Gas and Electric Co., Geosciences Department, P.O. Box 770000, Mail Code N4C, San Francisco, CA 94177

C. B. CROUSE, Dames and Moore, 2025 First Avenue, Suite 500, Seattle, WA 98121

James DIETERICH, United States Geological Survey, 345 Middlefield Road, MS 977, Menlo Park, CA 94025

Thomas JORDAN, Massachusetts Institute of Technology, Department of Earth, Atmospheric and Planetary Sciences, Cambridge, MA 02139

Shirley MATTINGLY, FEMA Region 9, Bldg. 105, Presidio of San Francisco, CA 94129

Dennis MILETI, University of Colorado, Natural Hazards Research and Applications Information Center, Institute of Behavioral Science #6, Campus Box 482, Boulder, CO 80309-0482

Barbara ROMANOWICZ, University of California, Berkeley, Department of Geology and Geophysics, Berkeley, CA 94720

John RUNDLE, University of Colorado, Department of Geology, CIRES, Boulder, CO 80309

Kaye SHEDLOCK, United States Geological Survey, Denver Federal Center, MS 966, Denver, CO 80225

Cheryl TATEISHI, California Governor's Office of Emergency Services, 74 North Pasadena Avenue, West Annex, 8th Floor, Pasadena, CA 91102

Susan TUBBESING, EERI, 499 14th St., Suite 320, Oakland, CA 94612-1902

Southern California Earthquake Center
Senior Research Investigators (1996)

Principal Investigator and Center Director:

Thomas L. Henyey
Department of Earth Sciences
University of Southern California
Los Angeles, California 90089

Co-Principal Investigator and Science Director:

David D. Jackson
Department of Earth and Space Sciences
University of California
Los Angeles, California 90024

Principal Institutions	Scientists
University of Southern California Department of Earth Sciences Los Angeles, California 90089	Keiiti Aki Yehuda Ben-Zion James Chin James F. Dolan Edward Field Anshu Jin Yong-Gang Li David Okaya Charles G. Sammis Ta-liang Teng
University of Southern California Department of Civil Engineering Los Angeles, California 90089	Geoffrey R. Martin
California Institute of Technology Seismological Laboratory Pasadena, California 91125	Robert Clayton Michael Gurnis John Hall Egill Hauksson Thomas Heaton Donald Helmberger Hiroo Kanamori Kerry Sieh Joann Stock
Columbia University Lamont-Doherty Earth Observatory Palisades, New York 10964	John Armbruster Roger Buck William Menke Leonardo Seeber Chris Sorlien Lynn Sykes
University of California Department of Earth and Space Sciences Los Angeles, California 90024	Paul Davis Monica Kohler Zheng-kang Shen Li-Yu Sung

University of California Institute of Geophysics and Planetary Physics Los Angeles, California 90024	Yan Kagan Leon Knopoff Stefan Nielson
University of California Department of Civil Engineering Los Angeles, California 90024	Mladen Vucetic
University of California Scripps Institution of Oceanography LaJolla, California 92093	Duncan Agnew Yehuda Bock Hadley Johnson Bernard Minster Peter Shearer Frank Vernon Nadya Williams Frank Wyatt
University of California Department of Geological Sciences Santa Barbara, California 93106	Ralph Archuleta Scott Hornafius Marc Kamerling Edward Keller Bruce Luyendyk Craig Nicholson Kim Olsen Peter Rodgers Jamie Steidl Alexei Tumarkin Alla Tumarkina

Member Institutions	**Scientists**
University of California Department of Earth Sciences Riverside, California 90024	Stephen Park
University of California Earth Sciences Board of Studies Santa Cruz, California 95064	Steven Ward
California State University Department of Geology Fullerton, California 92407	Mary Templeton
California State University Department of Geology San Bernardino, California 92407	Sally McGill
Central Washington University Department of Geology Ellensburg, Washington 98926	Charles Rubin
Chapman College Orange, California	Lisa Grant

University of Colorado Department of Geological Sciences Boulder, CO 80309	Karl Mueller
Harvard University Department of Earth and Planetary Sciences Cambridge, Massachusetts 02138	James Rice
Jet Propulsion Laboratory Pasadena, California	Danan Dong Andrea Donnellan
Massachusetts Institute of Technology Department of Earth, Atmospheric, and Planetary Sciences Cambridge, Massachusetts 02139	Brad Hager Tom Herring Robert King Robert Reilinger
Harvey Mudd College Claremont, California	Gregory Lyzenga
University of Nevada Department of Geological Sciences Reno, Nevada 89557	John Anderson Raj Siddharthan Feng Su Steven Wesnousky Yue-hua Zeng
Northern Arizona University Flagstaff, Arizona	Ernest Duebendorfer
University of Oregon Department of Geological Sciences Eugene, Oregon 97403	Gene Humphreys
Oregon State University Department of Geosciences Corvallis, Oregon 97331	Gary Huftile Jon Kimerling Robert Yeats
Princeton University Department of Geological and Geophysical Sciences Princeton, New Jersey 08544	John Suppe
San Diego State University Department of Geological Sciences San Diego, California 92182	Steven Day Harold Magistrale Thomas Rockwell
Stanford University Department of Civil Engineering Palo Alto, CA	C. Allin Cornell
Woods Hole Oceanographic Institute Department of Geology and Geophysics Woods Hole, Massachusetts 02543	Jian Lin

Industry Participants	Scientists
Pacific Engineering (Consultant)	Norman Abrahamson
Davis and Namson Ventura, California	Thom Davis Jay Namson
Leighton and Associates Diamond Bar, California	Eldon Gath
Harza Engineering Pasadena, California	Scott Lindvall
Maxwell Labs La Jolla, California	Keith McLaughlin
Vortex Rock Consultants Diamond Bar, California	Mehrdad Mahdyiar
Woodward-Clyde Associates Pasadena, California	Chandon Saikia Paul Somerville

International Participants	
CICISE/Ensenada, Mexico	Juan Madrid
Institut de Physique du Globe Paris, France	Geoffrey King

SCEC Research Priorities and 1997 Science Plan

Dave Jackson, Science Director
Southern California Earthquake Center

The Southern California Earthquake Center's mission is to promote earthquake hazard reduction by defining when and where future damaging earthquakes are likely to occur in southern California, calculating expected ground motion, and communicating this information to the community at large. In our studies of earthquake hazards we attempt to answer four major questions: (1) On which faults will future earthquakes occur, and the how large could these earthquakes be? (2) What is the average rate of earthquake occurrence on these structures, as a function of size, and are there circumstances that would cause present earthquake probabilities to be abnormal? (3) What are the characteristics of earthquake rupture, and how do these characteristics affect the emitted seismic waves? and (4) How do propagation and site effects influence the ground motion at a given site?

To answer these questions we have formed eight disciplinary groups. These are listed, with their Group Leaders and their email addresses, below:

Group A:	Master Model, David Jackson, djackson@ucla.edu
Group B:	Ground Motion Prediction, Steve Day, day@moho.sdsu.edu
Group C:	Earthquake Geology, Kerry Sieh, sieh@seismo.gps.caltech.edu
Group D:	Subsurface Imaging and Tectonics, Rob Clayton, clay@seismo.gps.caltech.edu
Group E:	Crustal Deformation, Ken Hudnut, hudnut@seismo.gps.caltech.edu
Group F:	Seismicity and Source Processes, Egill Hauksson, hauksson@gps.caltech.edu
Group G:	Physics of Earthquakes, Leon Knopoff, lknopoff@cyclop.ess.ucla.edu
Group H:	Engineering Applications, Geoff Martin, geomar@usc.edu

Normally we formulate specific research objectives and plans for each group at the Annual Meeting in the Fall. This year we plan to begin to discuss research priorities by email and other means before the Annual Meeting in Palm Springs (Oct. 20-22). We will formulate the research plan at the annual meeting as before, but we hope to communicate our general priorities, and benefit from your input, before then. This memo introduces some general themes, and the Working Group leaders will be adding specific plans for how each group can best meet the overall objectives. The Request for Proposals will be circulated about November 1, 1996, with proposals due about Dec. 6.

The general themes have evolved from the Phase II report (Seismic Hazard for Southern California: Future earthquakes 1994-2024, BSSA, 1995), issues identified in preparing the Phase III report, and the site visit held by NSF and USGS in response to our sixth year renewal proposal for funding through 2002.

The Phase II source model predicts a rate of magnitude 7 and larger earthquakes about twice the rate observed since 1850. About half of the predicted large earthquakes should be characteristic earthquakes on the San Andreas, San Jacinto, and Elsinore faults, while most of the observed large events have been off those faults (for example, the 1927 Lompoc, the 1952 Kern County, and the 1992 Landers events). Some ideas to explain the apparent discrepancy include (1) some fault slip has occurred by aseismic creep, so the model earthquake rates should be adjusted downward to allow for the aseismic fraction of fault slip; (2) the earthquake rate varies with time, lower than average in the last 150 years, and the rate should increase sometime, or (3) some of the geologically observed fault slip has occurred in earthquakes larger than the characteristic magnitudes in the Phase II model, so that the model over-predicted the rate of characteristic earthquakes while under-predicting the rate of even larger ones, or (4) the historic catalog of earthquakes is incomplete, and the actual rate has been higher than the catalog reveals. A major priority of the Earthquake Center will be to resolve this discrepancy, investigating whether aseismic creep could have occurred on the major faults in recent geologic time, whether specific models of time-dependent earthquake rate could explain a lower than average rate over the last 150 years, whether earthquakes greater than the characteristic magnitudes have occurred in southern California, and whether large earthquakes might have escaped detection.

Another question that follows from the Phase II report is the geometry of blind thrust faults in southern California.. We have now a rather detailed but controversial "thin skin" model of blind thrust geometry based on the method of balanced cross sections. The model implies sub-horizontal detachments and kink-band surfaces which might rupture in large earthquakes. There are competing "thick skin" models, but none are yet described in adequate detail for specific seismic hazard models. In the coming years we hope to refine the alternative hypotheses and devise definitive tests. Each of the models has geologic, geodetic, and seismological consequences that could be used to test them.

The concept of segmentation pervades seismic hazard calculations. We use it in estimating characteristic magnitudes on specific fault segments, and these magnitudes then help to control the long-term rate of earthquake occurrence. Segment boundaries may control the dynamics of rupture, the slip distribution in a given earthquake, the radiated seismic waves, the stress pattern left after the earthquake has occurred, and the interaction between separate faults and fault segments. The Center encourages research to better understand how segmentation works, to find ways to identify segment boundaries from available data, and to formulate testable hypotheses on the identity and role of segment boundaries. We also encourage research on the broader question of what limits rupture and the ultimate sizes of earthquakes.

In the future, earthquake hazard estimates will increasingly involve calculation of theoretical seismograms across a broad range of frequencies. Realistic seismograms require realistic models of rupture propagation, wave propagation and interference, and nonlinear interactions of strong ground motion with near-surface soils. To test theoretical seismograms we must explain observed ones. We have seen tremendous progress in modeling source, path, and site effects, but to date most studies consider the ingredients separately, assuming the other effects are adequately known. The Center encourages research to apply the Master Model concept using self-consistent rupture, wave propagation, and site effects models, including analysis of the non-uniqueness caused by uncertainties in the spatial and temporal characteristics of rupture, the seismic wave velocity distribution, and near surface geology.

Please address general comments on the research priorities to me. In the near future we will establish an internet bulletin board for your comments on general priorities, and if there is interest we may establish separate bulletin boards for individual working Groups.

SCEC Funding, 1991-1996

			Infrastructure			
	1991	1992	1993	1994	1995	1996
Management	240	225	223	240	260	290
Workshops/Meetings	45	90	60	100	98	110
Visitors	290	150	110	175	290	298
Data Center	297	200	181	225	225	210
Strong Motion Data Base	0	30	35	60	50	65
Broad Band Center	282	200	202	170	125	180
GPS Data Analysis	475	410	310	355	385	305.5
GIS	80	70	105	85	92	0
Earthquake Geology GIS	0	0	95	90	90	55
Education and Outreach	30	225	110	505	445	508.5
Pinon Flat	0	20	20	50	95	90
TERRAscope	0	60	60	55	50	50
Subtotal	1,739	1,680	1,511	2,110	2,205	2,162
Post Earthquake Studies			289	715		
			Science			
A/Master Model	150	223	299	432	475	412
B/Ground Motion Prediction	200	167	163	240	271	285
C/Earthquake Geology	200	399	281	465	442	474
D/Tectonics and Subsurface Imaging	275	170	82	506	261	299
E/ Crustal Deformation	160	117	136	141	237	289
F/Seismicity and Source Processes	145	150	145	205	157	150
G/Physics of Earthquake Sources	200	154	95	151	172	209
Subtotal	1,330	1,380	1,201	2,140	2,015	2,118
Total Obligated BY SCEC	3,069	3,060	3,000	4,965	4,220	4,280
Total Funding (NSF + USGS + FEMA)	3,250	2,879	3,000	4,965	4,245	4,255

1996 SCEC Projects

Principal Investigator	Title	Working Group
Abdouch (USC)	1996 SCEC Education Program	I
Abrahamson (Consultant)	Uncertainty in Probabilistic Hazard Analysis	A
Abrahamson (Consultant)	Coordination and Preparation of Phase III Report	A
Agnew (UCSD)	GPS Infrastructure: Data Archiving	E
Agnew, Johnson, H. & Wyatt (UCSD)	Understanding and Reducing Monument-Related Noise in Geodetic Measurements	E
Aki & Chin (USC)	The Validation of Coda-based Site Classification Map in Southern California	A
Anderson, Su & Zeng (UNR)	High Frequency Ground Motion by Regression and Simulation	B
Andrews (USC)	1996 SCEC Knowledge Transfer Program	I
Archuleta & Tumarkin (UCSB)	SCEC Strong-Motion Database SMDB and Empirical Green's Functions Library EGFL	I
Archuleta (UCSB)	Portable Broadband Instrumentation	I
Ben-Zion (USC)	Coupled Self-Organization of Seismicity Patterns and Networks of Faults, and Basis for Evaluating Seismic Risk and Precursors	A, G
Bock (UCSD)	Southern California Integrated GPS Network/Permanent GPS Geodetic Array (SCIGN/PGGA)	I
Clayton (Caltech)	SCEC Data Center Operations	I
Clayton (Caltech)	Analysis of LARSE Line 1 Onshore-Offshore Data	D
Cornell (Stanford)	Southern California Probabilistic Seismic Hazard Analysis	A
Davis, P. & Gao (UCLA)	Analysis of Northridge Aftershock Amplitudes and Damage	B
Davis, P. & Kohler (UCLA)	Integration and Analysis of LARSE Passive and Active Data, and Preparation for SMORSE	D
Day & Harris (SDSU)	Dynamic Modeling of Earthquakes on Inhomogeneous Faults	G
Day (SDSU) & Bielak (Carnegie Mellon)	Workshop on 3D Modeling of Earthquake Ground Motion in Sedimentary Basins	J
Day (SDSU) & McLaughlin (Maxwell)	Three-Dimensional Simulation of Long Period Ground Motion in L.A. Basin	B
Dolan (USC)	Preparation of SCEC Phase III	A
Dolan (USC)	Paleoseismology and Seismic Hazards of the Cucamonga Fault	C
Dong (JPL)	Mapping Horizontal Velocity Field in Southern California From the Combination of Geodetic Data	E
Donnellan (JPL) & Lyzenga (Harvey Mudd)	Geodetic Signals Expected from Fault Models in the Los Angeles Region	E
Duebendorfer (No. Arizona) & Davis, T. (Davis & Namson)	Determination and Analysis of Aseismic Deformation in the Upper Crust of Southern California	C, E
Field & Aki (USC)	Site Response from LARSE Data	B, D

1996 SCEC Projects

Gath & Munro (Leighton & Assoc.)	Neotectonic Uplift of the San Joaquin Hills Based on Marine Terrace Chronology, Orange County, California	C
Grant (Chapman)	Neotectonic Uplift, Quaternary Deformation and Earthquake Potential of the San Joaquin Hills, Orange County, California	C
Gurnis (Caltech)	Dynamic Models of the Geodetic Signals Expected for the Dense Network's AA' Line	E
Hager (MIT)	Continuum Mechanics Models of Blind Thrusts in the L.A. Basin	C, E
Hauksson & Kanamori (Caltech)	Towards, Real-Time, Routine Broadband Seismology	F
Hauksson (Caltech)	L.A. Basin Tomography with the LARSE and Northridge Datasets	D, F
Heaton & Hall (Caltech)	The Effects of Phase III Time Histories on Flexible Buildings	B
Henyey (USC)/Jackson (UCLA)	1996 Post-Doctoral and Visitor Program	I
Henyey (USC)/Jackson (UCLA)	1996 SCEC Management Operations	I
Henyey (USC)/Jackson (UCLA)	1996 SCEC Meetings and Workshops	I
Herring & King (MIT)	GPS Data Error Spectrum Analysis	E
Humphreys (Oregon)	The Fully 3-D Visco-Elastic Faulting Response: Coseismic Displacement, Post-Seismic Relaxation, and Time-Dependent Earthquake Shadowing	E
Humphreys (Oregon)	Modeling of the Southern California Deformation: An Initial Physical Master Model	D
Jackson, Kagan, Ge & Potter (UCLA)	Seismic Hazard Estimation	A
Jin & Aki (USC)	Study of Surface Layer Effects on Spectral Scaling Using Mojave Borehole Data	B, F
Kagan & Jackson (UCLA)	The Influence of Stress on Future Earthquakes	A, E
Kanamori & Hauksson (Caltech)	Enhancement of TERRAscope	I
Kanamori (Caltech)	Initiation of Earthquake Rupture	F
Keller & Gurrola (UCSB)	Earthquake Hazard of the Santa Barbara Fold Belt	C
King & Herring (MIT)	Support for GPS Analysis	I
King, Herring & Reilinger (MIT)	Geodetic Constraints on Interseismic, Coseismic, and Postseismic Deformation in Southern California	E
Knopoff (UCLA)	Model of Dynamic Fractures in a Continuum	A, G
Knopoff (UCLA)	Model of the Southern California Fault Network	G
Knopoff (UCLA)	Simulations of Dynamical In-Plane Rupture Source Effects	B, G
Li & Aki (USC)	Monitoring Post-Seismic Changes of the Landers Fault Using Fault-Zone Trapped Waves Excited by Explosions	D
Lin (WHOI) & King (IPG)	Investigation of 3-D Time-Dependent Coseismic and Postseismic Coulomb Stress Changes on the Southern San Andreas Fault and Blind-Thrust Systems in the Los Angeles Basin	A, E

Lindvall (Harza)	Paleoseismic Investigations of the Western Sierra Madre Fault Zone	C
Magistrale (SDSU)	Integrated Los Angeles Area Velocity Model	D
Mahdyiar (Vortex)	Probabilistic and Sensitivity Analysis of Ground Motion Parameters in Southern California	A
McGill (CSUSB)	Paleoseismic Studies of the San Andreas and Other Faults in the San Bernardino Area	C
Minster (UCSD)	ROC Curves for Intermediate-Term Earthquake Prediction Algorithms	A
Mueller (Colorado)	Structural Analysis of Active Folding and Blind Thrusting in the San Joaquin Hills	C
Mueller (Colorado)	Characterization of Active Faults in East Los Angeles	
Nielsen & Knopoff (UCLA)	Fault Geometry and Seismic Rupture	G
Okaya & Henyey (USC)	Crustal Setting of the Northridge Earthquake: Analysis of the LARSE Malibu-Northridge-West Mojave Transect (Line 2) Via Refraction and Wide Angle Reflection Methods	D
Okaya & Henyey (USC)	Structural Geometries of the Northridge Epicentral Region and Transverse Ranges Fold & Thrust System: Application of Industry Seismic Reflection Profiles	D
Olsen & Archuleta (UCSB)	Long-Period Site Response in the Los Angeles Basin from 3-D Simulations of Ground Motion	A, B
Park (UCR)	Phase III - Site Amplification Map Creation	A
Rice (Harvard)	New Methodology in Computational Seismology for Dynamic Rupture Along Complex Fault Systems	B, G
Rice (Harvard)	Elastodynamic Simulations of Rupture Propagation and Earthquake Sequences Along Complex Fault Systems	B, G
Rockwell (SDSU)	Paleoseismic Studies Along the Sierra Madre, San Fernando, and Santa Susana Faults	C
Rubin (Central Washington)	Paleoseismic Studies Along the Southern Flank of the Central Transverse Ranges: Slip Rates and Recurrence Interval on the Sierra Madre Segment	C
Scott & Sammis (USC)	A Granular Model of Earthquake Mechanics and Radiation	G
Seeber & Armbruster (Lamont)	Earthquakes, Faults, and Stress in Southern California	F
Shearer (UCSD)	Precision Relocation of Los Angeles Region Seismicity	F
Shen & Jackson (UCLA)	Tectonic Deformation in the Greater Los Angeles Region	E
Shen, Sung & Jackson (UCLA)	Geodetic Velocity Map	E
Sieh & Lilje (Caltech)	Computational Support for Paleoseismic and Neotectonic Studies	I
Sieh (Caltech)	Seismic Source Characteristics of the Southern San Andreas Fault and Related Structures: San	C
Sieh (Caltech)	Characterization of Active Faults in East Los Angeles	C
Steidl & Tumarkin (UCSB)	Response Spectral Amplification Factors: Correlation with Geological and Geotechnical Site Characteristics	A, B

1996 SCEC Projects

Stock (Caltech)	Compilation of New and Existing Stress Observations for Southern California	D
Sykes & Buck (Lamont)	Development of a Physical Model of Stresses in Southern California and Changes in Rates of Historic Seismicity as an Intermediate-Term Earthquake Precursor	A
Tumarkin & Archuleta (UCSB)	Empirical Time-Series Simulation of Phase-III Scenario Earthquakes	B
Vucetic (UCLA)	Densification and Enhancement of the SCEC Geotechnical Data Base	B
Ward (UCSC)	A Multidisciplinary Approach Toward the Master Hazard Model	A
Wesnousky (UNR)	Construction and Comparison of Seismic Hazard Maps	A
Wyatt & Agnew (UCSB)	Monitoring Structure Stability with Tiltmeters	E
Wyatt & Agnew (UCSB)	Pinon Flat Observatory - Continuous Monitoring of Crustal Deformation	E
Yeats & Huftile (OSU)	Northern Los Angeles Basin Configuration and Fault Geometry: A Study of Earthquake Paths	D, C
Zeng & Anderson (UNR)	Simulations of Ground Motion in the Los Angeles Basin: Simplified Approaches	A, B

SITE VISIT REPORT

Southern California Earthquake Center
University of Southern California

September 12, 1996

OVERVIEW

The Southern California Earthquake Center (SCEC) has been in existence for six years and is embarking on an ambitious program of earthquake research and education to take it into the next century. Consisting of 7 primary educational institutions, 19 participating educational institutions, 7 industrial participants, and 2 international participants including its funding partner, the U.S. Geological Survey, the SCEC has matured into a unique organization which has focused earthquake hazards research in a critical geographical area of the United States. There is no comparable geosciences organization anywhere in the world which is simultaneously attacking the fundamental scientific problem of earthquake occurrence and concomitant earthquake hazards mitigation.

Because of its location in southern California, one of the major seismogenic zones of North America, the SCEC has been positioned to take advantage of a unique natural laboratory to further its scientific goals. In its initial 6 years of existence, two major earthquakes have occurred in the region; the 1992 M7.3 Landers earthquake in the Mojave Desert, and the 1994 M6.7 Northridge earthquake north of the San Fernando Valley. The SCEC served to focus and organize scientific community response to these earthquakes which resulted not only in significant post-earthquake scientific studies, but also defined the major scientific issues of earthquake genesis in the region. Indeed, the Landers event was a major catalyst in the SCEC resulting in what they termed the "Phase II" report which was the first realization of the "master model" concept for earthquake hazards in southern California. Bringing together diverse geological and geophysical data, production of this report enabled SCEC scientists to pose the major questions that must be answered for understanding the earthquake hazards problem in the region and to direct future scientific efforts in its proposed next 5 years of existence. One of the most remarkable scientific achievements of the SCEC has been the measurement of the geologic strain rate field over southern California using Global Positioning System (GPS) and trilateration measurements. This strain map is unprecedented in its detail showing how deformation is distributed across the major fault systems and it played a principal role in development of earthquake recurrence models in the Phase II report.

The management structure of the Center underwent a number of significant changes upon the retirement of Scientific Director K. Aki earlier this year. An extensive search for his replacement and a reformulation of the management structure of the SCEC resulted in previous Executive Director, Prof. Thomas Henyey, being chosen as Principal Investigator/Center Director and position of Scientific Director being assumed by Prof. David D. Jackson of UCLA. The new arrangement precipitated other changes in the overall organizational chart in addition to splitting the management of SCEC between 2 separate institutions. The Site Visit Committee was interested in these changes and found that the new arrangement appeared to be working very well. The Committee is impressed with the current leadership and is enthusiastic that the new management structure will serve the SCEC well.

INTRINSIC MERIT OF THE STC RESEARCH

Quality of Individual Research Projects and Project Plans

The present proposal aims at refining the fundamental scientific issues identified in the preparation of Phase I, II and III reports. The results of the proposed research are to be used as future input to the next generation of hazard estimation procedures. The site review team endorses this definition of the Center mission for the next five years.

The overall quality of the proposed research is excellent. The series of questions raised in the proposal are fundamental, albeit difficult, ones that must be answered before significant advances in the prescription of seismic hazards can be made. These questions address the dynamics of seismic sources, the propagation of seismic waves in realistic, heterogeneous media and the local amplification of seismic waves. They have been key questions in the earthquake studies, and with the excellent, interdisciplinary team SCEC has put in place significant progress toward answering these question can be envisaged.

In the past five years, the SCEC has developed the necessary mechanisms for instigating mission-oriented, interdisciplinary and cooperative research. The basic data available include detailed seismicity, seismic velocity mapping using artificial and natural sources, GPS, numerical modeling, surface geologic mapping and time history of fault-slip etc. With the proposed expansion of the GPS network, the augmentation of the seismic network and other special projects, there should be an excellent database for the proposed research.

While the proposal is fairly thorough in describing the data needed to achieve the research objectives, the Site Visit Team feels that SCEC projects would benefit from better integration of existing seismic velocity models for southern California and the Los Angeles basin. In addition, better constraints on detailed basin structure (basement topography and S wave velocities in the upper 30-100 m in particular) are necessary for the next stage of wave propagation and site response studies. The Site Visit Team encourages SCEC scientists to develop a more explicit plan for obtaining this information in priority areas.

Quantity and Quality of Productivity to Date

The SCEC team consists of some of the most productive earth scientists in the nation. In addition to copious publications by many SCEC scientists through normal scientific channels, the SCEC has produced documents that have been well-accepted in the earthquake engineering community for building design, by CALTRANS for designing major infrastructures, by California Division of Mines and Geology for hazards mapping and by insurance companies for risk calculations.

SCEC scientists are tackling some of the major questions in tectonics and in seismic hazard estimation. For example, thin-skinned tectonics has been a dominant hypothesis in tectonics; its proponents have hypothesized the presence of a major detachment under Los Angeles. SCEC scientists have made attempts to evaluate whether this detachment exists. Thus in the study of hazards, a major geologic hypotheses is being tested. In terms of hazard estimation, fault segmentation has been used to determine maximum possible earthquakes along faults. Following post-earthquake studies of the Landers event, the segmentation hypothesis has been substantially modified. Future hazard estimation will be on a much firmer basis as a result.

Uniqueness of Research Contributions Within the Community

The combination of producing cutting-edge research and passing it along in a timely manner to users eager to apply such results is quite unique. Because the scientific understanding of faulting is quickly evolving, the SCEC group has to supply the information in a very sophisticated way. While keeping the information for societal consumption relatively stable, it attempts to put uncertainty estimates on the information, so that it can be properly used. While scientists can still pursue ultimate answers, the society benefits from up-to-date advances. This is a good model for the proper use of scientific information.

The partnership with the USGS is complementary and close cooperation and interaction with USGS scientists has resulted in the realization of many important projects. Together with USGS/Pasadena, SCEC carried out LARSE and published materials for publication on earthquake education. Further cooperation includes the implementation of the Southern California Integrated GPS network (SCIGN), the formulation of an earthquake response plan, and the establishment of a Los Angeles fold and fault database. SCEC workshops are highly useful to USGS personnel. USGS uses the SCEC infrastructure (data center and portable seismic instrumentation) quite extensively.

The California Division of Mines and Geology (CDMG) is the statutory government organization responsible for producing seismic hazard maps, for defining earthquake fault zones and for installation and maintenance of strong motion instruments. Joint SCEC/CDMG activities have enhanced and accelerated the interchange of ideas and the SCEC master model has been used extensively in CDMG hazard map preparation. SCEC, CDMG and USGS jointly develops consensus reports which are authoritative and useful to the non-scientific community.

The seismological community, as a whole, also interacts with SCEC scientists and benefits from SCEC infrastructure. The data center is, for example, open to all users. Thus, research seismologists can access data on the internet almost as quickly as SCEC scientists. The research methodology developed by SCEC can and is being applied elsewhere and it is obvious that scientific communication goes both ways, to the benefit of all involved.

IMPACT OF THE STC ON THE INFRASTRUCTURE OF SCIENCE AND ENGINEERING

Education Programs: Post-doc, Graduate, Undergraduate, K-12, Informal

Although the ratio of students and post-docs to senior investigators appears to vary widely between SCEC institutions, the SCEC as a whole has committed a substantial share of its resources to post-doc and graduate student training. Student and post-doc poster presentations revealed vigorous participation in many aspects of the SCEC's research. Students and post-docs were very positive about their access to important datasets and their scientific interactions within and between SCEC institutions (the monthly seminars in particular), and stressed that these opportunities would not exist without the Center. They were also pleased with their overall training as practicing scientists.

Under the very capable leadership of Curt Abdouch, the Center has embarked on an ambitious and innovative education program that spans K-12 and undergraduate audiences. They have wisely focused most of their activity on 9-12 and undergraduate education, and should be commended for the "hands-on" learning approach evidenced in most of their programs and educational materials. At the pre-college level they have concentrated on teacher training and have worked extensively with existing educational institutions such as the Palos Verdes School system, the Center for the Advancement of Precollege Science Education, and the Southern California Junior Academy of Sciences. These strategies will enhance the long-term impact of their education activities and will keep them aligned with evolving practices in science education. At the undergraduate level, they have developed an effective summer intern program. Undergraduate students were very enthusiastic about their research and the intern program and presented high quality posters describing their work. Many indicated that their work with the Center had greatly increased their access to research faculty and had made graduate school and careers in science seem both exciting and attainable.

Involvement of Females and Minorities in Science and Engineering

Relative to earth science programs within the United States, the SCEC has been reasonably successful in recruiting and retaining women in their education and research programs. The percentage of their current graduate students who are women (27%) is close to the national average for top-ranked geoscience departments reported by the National Research Council in 1995, and the undergraduate intern and post-doctoral programs have included significant numbers of women (54% overall of undergraduate interns and 15% overall and 25% in the current year of post-docs). Discussion with students and post-docs revealed that the climate for women and minorities within the SCEC is very positive. The number of women who participate in Center research as PI's or co-PI's (12%) is reasonable relative to national trends. In terms of scientific management, the Center appears to recognize that women are not well represented on the Board of Directors and among working group leaders. The Center is encouraged to remedy this situation over the next 5 years.

The numbers of under-represented minorities who participate in the Center's undergraduate, graduate and post-doctoral programs are small, as is the percentage of under-represented minorities among Center PI's and co-PI's (2.5%). These figures are not surprising given the small national numbers of under-represented minorities who graduate with earth science degrees. Nonetheless, the Center should work vigorously to increase the participation of under-represented minorities at all levels. The Site Review Committee felt that efforts directed towards high school, undergraduate and graduate audiences would be particularly effective. The Center is to be commended for their initial efforts in this direction such as the pre-college Summer VINE program.

Creation of Unique Facilities/Resources for Research Community's Use

The Center has been key to the creation of several new instrumentation facilities. It has pulled together three data centers: the Seismic Data Center (Caltech, USGS) for waveform data and earthquake parameters, the GPS Data Center (UCSD, UCLA, MIT) for GPS survey data, and the Strong Motion Data Center (UCSB) for strong motion data and the Empirical Green's Function Library. Overall, the data centers appear to have grappled successfully with the important issue of data quality control, although instrument calibration problems persist in waveform data from portable instrument aftershock deployments. The Center has made their data and data products available accessible to a wide variety of users through a number of interfaces, and Center data appears to be widely utilized within the earthquake research and broader user communities. The Center has also assembled 20 portable broadband recorder/sensor systems (housed at UCSB) which are heavily used for a variety of earthquake studies in southern California.

The proposed Southern California Integrated GPS Network (SCIGN) is a very significant instrumentation program which has the potential to lead to new discoveries regarding the regional strain field and which would not exist without the Center's leadership. The Center is also actively involved in the planned upgrade of the Southern California Seismic Network which will greatly densify station distribution, particularly in more densely populated areas. The Site Review Committee had mixed opinions about the scientific utility of the proposed deployment of nine borehole stations over three years. The Center is encouraged to evaluate this program carefully after the deployment of the initial year's stations.

Linkages to Other Academic Institutions and to Non-Academic Sectors

The Center has forged strong relationships with a wide variety of agencies and institutions active in earthquake hazard research and planning including the California Division of Mines and Geology, FEMA, the State of California, the City and County of Los Angeles, Caltrans, the insurance industry, and earthquake engineering companies. In addition to their education program, the Center has enhanced their links to other academic and research institutions with their visiting scientist program.

Leadership in the Research Community

The Center has provided strong focus and initiative to interdisciplinary research on the quantification of southern California earthquake hazards. They have contributed organization and resources to post-earthquake research efforts, although more comprehensive pre-planning of post-earthquake activities is desirable. The Center has also taken the lead in generating new funding for large instrumentation activities such as SCIGN, and has improved the interface between earthquake scientists and the earthquake engineering community.

IMPACT OF THE CENTER MODE OF SUPPORT

Degree and Kind of Interdisciplinary and Interorganizational Collaboration.

The SCEC has assembled an excellent group of researchers, with excellent scientific leadership because it has been able to draw on the personnel of the participating institutions via the center structure. In addition, the acquisition and organization of the material resources needed to attack a large scientific problem of great societal importance would not have been likely through the efforts of any single institution. The participants recognize as an important value the center's ability to re-program funds to meet unexpected research opportunities, such as the rapid deployment to investigate a strong earthquake within their study region.

The center mode of support has greatly facilitated the integration of the several disciplines (seismology, geology, geophysical methods of crustal study, geodesy) for the development of the master earthquake model. The need for inputs from all of these fields has long been recognized, but the effective implementation of the required collaboration has been slow. The SCEC has made an important contribution here. As an example, we find field geologists and earthquake physicists sharing ideas at a level not often seen.

The close interactions among the core institutions of the SCEC has been a force for progress toward the mission. Equally impressive is the collaboration with the California Division of Mines and Geology, which now views the SCEC as an integral part of the California effort to reduce loses from earthquakes. CDMG acknowledges that the existence of SCEC has accelerated the exchange of information and the integration of ideas. Similarly, the SCEC has worked closely with the USGS on major projects, such as the Los Angeles Regional Seismic Experiment (LARSE), and its programs of education and outreach are strong supplements to the efforts of the USGS.

The unified data centers and the pools of instrumentation have served as a bond among the participating institutions, as well as a benefit to many researchers outside of the SCEC structure. The network of GPS receivers (SCIGN), which will be an important tool in the pursuit of the understanding of earthquake physics, would not exist without the coordination of effort provided by the SCEC.

Undergraduate and graduate students emphasize that the SCEC has promoted interactions among the students of all the participating universities that had never happened prior to the formation of the SCEC. They appreciate that they have been able not only to share ideas about research, but to form bonds that may well extend into their careers. The quality and number of participants in the education and knowledge-transfer programs could not be as great without the center organizational structure.

Degree and Kinds of Contributions Beyond a Collection of Individual Projects.

A listing of all of the contributions that represent the results of inter-institution cooperation through the center mode of support would require a list of almost all of the major achievements of the SCEC. Prominent among these are: the Phase I and Phase II published reports, and the soon-to-completed Phase III report. The progress toward the development of the master model would not have been possible without the center structure. LARSE and SCIGN could have been implemented only through the center mode of support.

The SCEC data centers are a model of the type of comprehensive regional data centers, in which a great array of applicable data is available to all users, without proprietary constraints imposed by the data managers, that are needed in all of the seismic regions of the nation.

UTILITY OR RELEVANCE OF THE RESEARCH

Creation of a Unique Research Theme and Environment Within Community

The unique theme of the SCEC is embodied in the "master model" approach, wherein there is a determination to fully integrate geology, seismology, geodesy, and mechanical modeling in ways that address process-oriented understanding of earthquake rupture, the partitioning of seismic and aseismic slip across fault systems, and the interaction of seismic waves with complex local structures. To what end?: Estimating the likelihood of earthquakes as a function of location, magnitude, and time within the heavily populated region of southern California, in order to reduce loss of property and human life. The theme is critical for understanding the occurrence of major earthquakes and associated hazards in southern California. It would be foolhardy for California and the nation NOT to vigorously address this threat through basic scientific research.

The unique environment is one of close cooperative interaction among individuals drawn from different disciplines and academic institutions. The environment also includes partnership with other critical entities (e.g., California Division of Mines and Geology, U.S. Geological Survey, CALTRANS, FEMA, City and County of Los Angeles) such that there is an acceleration in the rate of interchange of ideas. There is thus created a massive, focused study on a limited region, and out of this is produced a depth and breadth of understanding that would be impossible to achieve through traditional or conventional means.

Moreover, the uniqueness of the environment includes a significant knowledge-transfer mission designed to convey information and knowledge to end users, notably urban planners, the insurance industry, engineers, and citizens. Rather than a one-way service thrust, the outreach mission imposes a research-results, "bottom-line" dimension that has truly enhanced the basic science achievements of the SCEC.

The ongoing and increasing success of the SCEC in interpreting its Master Model theme to agencies, leaders, and citizens in Los Angeles carries with it increasing expectations regarding delivery. Meanwhile, the SCEC scientific leadership is recognizing that deeper probing of fundamental basic scientific relationships is the path to reaching ultimate objectives. This juxtaposition poses an especially challenging requirement during the next phases of work, namely, to simultaneously carry out the deeper basic science and statistical analysis while at the same time generating (through partnerships) tangible practical products that meet the increased expectations held by end users.

Impact of Research Contributions on the Research Community

The principal contributions to the research community come in several substantive forms: publications authored by principal investigators and their colleagues, including post-docs and students; major SCEC technical publications; and data sets that are available to anyone interested in utilizing them. The list of peer-reviewed publications is impressive in number, scope, and quality. Titles are published in the SCEC Quarterly Newsletter, and as of summer '96 they numbered 340. Many of the publications receive close attention by the broader research community in part because of the recognized stature of the individual scientists participating in the SCEC. These are among the world leaders in seismological and active tectonics research. Major SCEC technical publications that impact the larger research community include SCEC Earthquake Hazards Reports, including such major contributions as the 1995 piece entitled "Seismic hazards in Southern California: Probable earthquakes 1994-2024. " Technical publications such as these are sufficiently daring to address earthquake probability issues such as: Where and how big? How often and when? What happens during rupture? What happens at the site? The foundation for approaching these questions is fundamental science and statistical analysis, and without question these topics receive attention and critical review of colleagues outside of the SCEC and stimulate new ideas and projects.

A legacy of the SCEC is the already burgeoning quality-controlled data sets (GPS, seismic, fault maps, ...) and models (faults and slip rates, wave forms, empirical Green's functions, seismic velocity, crustal deformation, ...) available to all researchers. This type of community data product avoids repetition of research effort and provides a forum for interaction among researchers. It is hard to imagine how the sharing of ideas, research results, instrumentation, and data archiving resources evidenced in the Center's work could exist without a centralized administrative structure.

Another major contribution is face-to-face interaction with scientific colleagues, achieved commonly through workshops and seminars at sites of those colleagues being served. Examples include workshops at USGS in Boulder, FEMA in Washington, D.C., and the Natural Hazards Research Application and Information Center in Boulder.

Quality and Quantity of Knowledge/Technology Transfer to Non-academic Sectors

The SCEC knowledge and technology transfer program has been built within just a two-year period of time through enlightened crafting of a business plan and a series of strategic choices. The program emphasizes personal contact, products, and partnerships/alliances. It has been constructed with the objective of being "transportable" to other science and technology entities beyond the SCEC that are serious about effective mission outreach to end users. The program has clearly identified its end users, has incisively drawn a distinction between information transfer (to some users) and knowledge transfer (to other users). The heart of the planning thrust has been a Research Utilization Council that works to identify SCEC source strengths and the needs and interests of user groups. The primary goal of the knowledge transfer program is to promote earthquake hazard reduction. The expression of the knowledge transfer program takes many forms: workshops, conferences, seminars, field trips, planning meetings, newsletters, publications, WWW interaction, etc. In the same way that the individuals entrusted for SCEC Center leadership (Henyey), Science leadership (Jackson), and Education leadership (Abdouch) have been well chosen, the knowledge transfer program is in good hands under the leadership of Jill Andrews.

Without an effective knowledge transfer program, the SCEC would not achieve its goals. With its remarkably effective emerging program, the SCEC is creating a legacy of essential outreach to southern California and beyond.

INSTITUTIONAL SUPPORT AND CENTER MANAGEMENT.

Financial and In-Kind Support Beyond NSF

During the past six years the Center has done an outstanding job at raising funds from non-STC sources. They have had both solid financial and in-kind commitments from the core institutions. They have significant annual funds from the USGS that match one-half to one-third of NSF funds and have obtained funds from other organizations. In 1996 they went after and received $1.4 M from NASA for purchase and installation of 30 GPS receivers. They have also gone after $2 M in funding from the Instrumentation and Facilities Division and the Academic Research Infrastructure of NSF to support the installation of an additional 50 sites. If received, this and other non-STC funding will be a significant boost to the funding revenues of SCEC from STC. They have also acquired funding from other Federal Agencies (e.g., FEMA), some state, county and city, and the private sector. These additional funds significantly leverage the STC funds.

As has occurred over the past six years, SCEC continues to obtained financial support from other Federal Agencies. During 1997 it is anticipated that the contributions from other Federal Agencies will be in excess of $4.5 M. These agencies are other divisions of NSF, NASA, and USGS. The California Department of Transportation is funding SCEC during 1997 and 1998 at $750,000 per year, again leveraging the NSF/STC funds. The Center has the opportunity to obtain significant funding from the Keck Foundation, a non-profit organization, that may amount to as much as $1 M or more during the next five years.

In reviewing the Center's financial support sources, it was obvious that there was one major sponsor missing. That sponsor is the State of California. While it is recognized that the State of California is indirectly contributing some funding and in-kind services through the core institutions that are state owned and more directly through the California Department of Transportation, this Site Review Team feels that the State of California should be funding the Center at a larger level. This belief is based on the fact that the Center's program is problem focused research, known as the Master Model, for the purpose of understanding the earthquake hazard in the Los Angeles basin that in the long term will lead to mitigating the earthquake risk and saving thousands to possibly millions of California lives. The question the review team puts to the Center Management is: Why should the tax payers of the Nation be funding a program to the amount of nearly $8M in 1997 compared to the state's total contribution of about $2 M, when the gains over the next five to ten years will be of primary benefit to only California? The Site Review Team recommends that the Center Management make a concerted effort to obtain substantial funding from the State of California.

Prospects for Continuation Beyond 11-Year STC Funding

The SCEC Program is an outstanding, problem focused research program integrating many disciplines together to solve the unique problem of understanding the seismic hazard of the Los Angeles Basin, in particular, and of Southern California as a whole. While great advances will be made in the next five years, full understanding of the seismic hazard will be far from complete. Thus, in preparing for Year-11 and beyond SCEC should principally stay the course and continue to improve the Master Model. Over the long term, SCEC successes will lead to mitigation of the earthquake threat and potentially save thousands of lives.

The Site Review Team recognizes that SCEC is a unique program that has established a niche in the world of earthquake hazards mitigation and understanding. However, it is also recognized that the success of SCEC will result in others trying to emulate it and at the same time challenge SCEC for the same funds. This is inevitable. However, such competition can and should be quite healthy to SCEC in the long term.

Stability and Creativity of Center Management Mechanisms

The Center Management has done an outstanding job the past six years in managing a complex and diverse program that constructing the Master Model requires. The Center Management has created a synergistic effect within the program that can be emulated by other centers. Center Management and its mechanisms have been extremely stable during the first six years. However, this year Science Director, Prof. K. Aki retired. The search for his replacement resulted in a reformulation of the management structure where Prof. Thomas Henyey of USC was chosen as Principal Investigator/Center Director with position of Scientific Director being assumed by Prof. David Jackson of UCLA. From the Site Visit Team's view, this change was a smooth transition. Other changes have occurred in the Center and Science Director's responsibilities. The Site Visit Team see these changes as positive.

It is the Site Visit Team's view that the Center Management have been extremely creative in its management style that has taken a collection of independent, highly talented individuals and created synergisms for team workmanship unheard of in the scientific arena. As a result, individual researchers now work more effectively as a team than as individuals and have made great strides in the development of new science.

The Site Review Team agrees with the Advisory Panel recommendation that the Center develop a strategic plan. The Center Management should always be looking ahead for being prepared for the potential of losing key people. Thus, Center Management should be always considering different funding and personnel scenarios in its planning activities.

ANALYSIS OF PROPOSED BUDGET AND BUDGET JUSTIFICATION

The SCEC is requesting $16.7M from NSF over the next 5 years. In addition, SCEC is expecting to receive approximately $6M from the U.S. Geological Survey for center activities. Other sources of funds include $2.25M from CALTRANS related to engineering projects, $2M from the NSF/ARI program and $1.4M from NASA related to the SCIGN initiative, and a modest amount from FEMA related to knowledge transfer/outreach. There also seems to be a good possibility that the SCEC will be awarded Keck Foundation funds associated with the SCIGN project.

Aside from funds being collected for the SCIGN special project, SCEC funds are apportioned by policy decision into 50% science, 40% infrastructure/management, and 10% outreach/education. This split appears to be an effective way to manage the budget for the diverse activities of a major Science and Technology Center.

The science budget supports about 50 Principal Investigators at an average level of only about $33K per investigator. This level of funding is generally used to support graduate students but is very effective at leveraging scientific support from member institutions, individual scientific budgets of P.I.s, and support from outside funding agencies. These very modest grants are a measure of the intensity of interest of P.I.s to participate in Center activities and are a very effective way of focusing the scientific effort.

A large part of the budget goes for support and construction of the scientific infrastructure of the Center. This includes SCEC data centers and instrumentation facilities mentioned above. The infrastructure budget is justified from both a scientific and institutional point of view. Scientifically, SCEC GPS and seismic facilities represent the cutting edge in technology and are needed to address the difficult problems of earthquake hazards mitigation in southern California. In addition, data from SCEC facilities are openly available to the scientific community through the three data centers and are valuable national and international assets in the fields of Geodesy, Seismology, Geology, and Earthquake Engineering. Indeed, SCEC data products are accessed by more scientists outside of the center than from within.

Although the Outreach and Education portion of the budget is the smallest general category within the center, it is a very important function and is pursued at a similar funding level as done at other NSF Science and Technology Centers.

Because of recent events related to the federal budget, there is currently a concern among members of the scientific community that continuous federal support of science is at risk in the near future. It is encouraging to see the SCEC address this concern by diversifying its budget base. New initiatives for major scientific upgrades of existing networks are being approached from a "special projects" point of view where funding is being pursued in a focused effort separate from the normal SCEC budget (e.g., the SCIGN project). However, the visiting committee recognizes a potential problem with this approach where requested outside funding may be insufficient to cover the proposed scope of the special project. In these cases, the committee encourages SCEC management to carefully reexamine scientific priorities to minimize detrimental effects on the general scientific/infrastructure budget.

An indirect, but very important, aspect of institutional involvement in the management of the SCEC is the role that USC plays as being the lead institution for SCEC funding. Moneys for the SCEC flow through USC to participating institutions without any tax of university overhead. This is very effective at maximizing the amount of funds available for researchers and furthering center scientific goals that might not otherwise be available if another university were the lead institution.

RECOMMENDATION

Summary of Strengths and Weakness

The intrinsic merit of scientific research at the Southern California Earthquake Center over the past 6 years and that proposed for the next 5 is of the highest caliber. Research at the Center is defining many of the major problems in the interdisciplinary fields of earthquake science and hazards mitigation.

The Site Visit Committee enthusiastically endorses SCEC's proposed science plan defining its mission for the next 5 years.

However, as in any activity with finite funds, there are limits to the problems that a STC can address. The Visiting Committee noted a few areas of scientific inquiry in the present program which could be re-evaluated or re-prioritized. These included construction of a unified velocity model for the Los Angeles Basin, developing an approach for determining near-surface seismic velocity structure for seismic hazards mapping, and a cost/benefit analysis for installation of the 3 borehole accelerograph arrays.

The SCEC has had a tremendous impact on the infrastructure of earthquake science and engineering. The SCEC's construction of regional seismic, GPS, and strong ground motion data centers is a model of excellence that can be used in other regions of the U.S. and would not have been possible without the STC program. The SCEC's efforts in education and outreach are also excellent and exciting. The climate for graduate and post-graduate research in earthquake science in southern California has improved immensely since the inception of the SCEC. However, like many institutions in science and education across the nation, participation of under-represented minorities in SCEC activities is relatively low. As the SCEC management recognizes, women are also under-represented on the Board of Directors and as working group leaders. Thus, *The Site Visit Committee encourages the SCEC to seek greater participation by women scientists in SCEC management and to increase participation of under-represented minorities at all levels, with particular emphasis on SCEC education and outreach activities.*

Additionally, the Site Visit Committee was impressed by outreach and education efforts that have developed over the past 2 years under the able leadership of Curt Abdouch. The SCEC is highly relevant to the general community in southern California because of the persistent problems of earthquake hazards there. SCEC's outreach program is unique and is being used as a model for earthquake-prone regions elsewhere.

The Site Visit Committee was particularly sensitive to budget issues since the climate for Federal Research dollars has been significantly degrading over the past several years.

The Site Visit Committee encourages the SCEC management to continue its efforts at diversifying its sources of support for Center activities over and above NSF STC support.

In addition,

The Site Visit Committee recommends that the SCEC management make a concerted effort to obtain substantial funding from the State of California.

This last recommendation follows simply from the constituency that is benefited directly by SCEC research and products. The committee believes that such diversification of support will be needed for SCEC to continue as a mature Center beyond the 11-year STC funding.

The SCEC is trying other approaches at procuring funds for large focused scientific efforts through special committees organizing scientific personnel and writing proposals to several different funding agencies. This "special projects" approach seems to be successful with the new SCIGN project but does carry some possible dangers, particularly if funding falls significantly short of the goal. The tendency may be to reprogram STC moneys for the special project at the expense of the scientific program. In these cases,

The Site Visit Committee encourages SCEC management to carefully reexamine scientific priorities in light of changes in funding for a special project to minimize detrimental effects on the general scientific/infrastructure budget.

In an effort to address these funding scenarios directly,

The Site Visit Committee agrees with the Advisory Panel recommendation that the Center develop a strategic plan.

Finally, the SCEC underwent significant changes in management personnel this year with the retirement of K. Aki and appointment of Thomas Henyey as Principal Investigator/Center Director and David Jackson as Scientific Director. This change in management was seen to occur smoothly and without detriment to the Center.

The Site Visit Committee congratulates retired Scientific Director Aki for his vision and service in helping to build the SCEC and has full confidence in new Center Director Henyey and Scientific Director Jackson for guiding SCEC through the next 5 years.

Funding Recommendation

Support as requested.

SITE VISIT REPORT

SOUTHERN CALIFORNIA EARTHQUAKE CENTER

SIGNATURE PAGE

AUGUST 28, 1996

______________________ Dr. James E. Beavers, MS Technology Inc.

______________________ Prof. George H. Davis, University of Arizona

Karen M. Fischer ______________________ Prof. Karen M. Fischer, Brown University

Carl Kisslinger ______________________ Prof. Carl Kisslinger, University of Colorado

Charles A. Langston ______________________ Prof. Charles A. Langston, Pennsylvania State University

Francis T. Wu ______________________ Prof. Francis T. Wu, SUNY at Binghamton

NSF STAFF

James H. Whitcomb ______________________ Dr. James H. Whitcomb, Program Director for Geophysics

SCEC's Global Science Classroom Learning Center

Curt Abdouch
Director of Education, Southern California Earthquake Center
University of Southern California

The Southern California Earthquake Center (SCEC) Global Science Classroom made a strategic shift in 1996 to concentrate on undergraduate services and activities, school district partnerships that promote systemic restructuring of science education and the development SCEC-specific educational materials. The SCEC Global Science Classroom Learning Center features prototypes of mechanical exhibits that demonstrate earthquake-related phenomena and concepts. These exhibits will be further field-tested in several southern California museums over 1997. The development of the prototypes was facilitated by Heads and Hands Edutainment, Inc. in Reno, Nevada, which was awarded a SCEC educational subcontract in 1995 through SCEC's funding from the Federal Emergency Management Agency (FEMA). The Learning Center also includes previews of two "SCEC Science Modules", educational units that will be used by students at secondary and undergraduate levels. These modules, which are the first of at least nine that will be developed over the next four years, highlight the work of SCEC scientists in the Crustal Deformation and the Seismicity and Source Processes Working Groups. Much of the educational content in the modules will be delivered to classrooms by the Internet and also will feature computer software (CD ROM) and hands-on science kits. The visualization tools, graphics, animations and SCEC data sets in the modules have been developed in part or in toto by undergraduate students in the SCEC Summer Intern Initiative over the last two years.

Dynamic Analysis of a Model Earthquake with Landers-like Properties

Mark S. Abinante
University of California, Los Angeles

The northward growth of the 1992 Landers earthquake was significantly delayed at the junction of two segments of the fault. We investigate the dynamics of rupture that takes into account the delays due to such an interior, breakable barrier and discuss its implications with regard to the final slip and state of stress along the fault.

We model a Landers-like earthquake as a 2-D crack whose prestress is everywhere equal to its critical fracture strength, except for unbreakable barriers at the ends and a significant but breakable barrier in the interior. To prevent overshoot rebound, we let the stress drop be significantly smaller than the prestress. Freezing initiates when and where the collision of the stress waves from the two ends of the first segment takes place; freezing is interrupted when stress waves from the breakthrough of the middle barrier reach the locus of healing. A very large stress heterogeneity is frozen into the fault at the conclusion of the earthquake, not at the middle barrier, but at sites where the various wave processes intersect. The exact nature of the stress anomaly depends on whether or not the already frozen region reruptures after the breakthrough of the middle barrier.

The Southern California Earthquake Center Knowledge Transfer Program

Jill Andrews, Knowledge Transfer Director and **Mark Benthien**, Outreach Specialist
Southern California Earthquake Center
University of Southern California

The Southern California Earthquake Center (SCEC) Mission

The Southern California Earthquake Center's mission is to promote earthquake hazard reduction by defining when and where future damaging earthquakes are likely to occur in southern California, calculating expected ground motion, and communicating this information to the community at large.

SCEC Knowledge Transfer

The SCEC administration actively encourages collaboration among scientists, government officials, and industry. Users of SCEC scientific products (scientific reports, newsletters, education curricula, databases, maps, etc.) include disaster preparedness officials, practicing design professionals, policy makers, southern California business communities and industries, local, state and federal government agencies, the media, and the general public.

Knowledge transfer activities consist of end-user forums and workshops, discussions among groups of end users and center scientists, written documentation and publication of such interactions, and coordination of the development of end user-compatible products.

Planned and In-Progress Products and Projects include:

- Insurance Industry Workshops: Assessing Seismic Risk in Southern California.
- Media Workshops.
- Field Trips.
- Quarterly newsletter.
- WWW SCEC Home Page and Internet Access.
- Publications; Scientific Reports.
- Multimedia Earthquake Information System (Internet, Packet radio, PC-Pager, Text-Pager; GIS Format, Open-Architecture Design Allowing for Multiple Database Access).
- Private Industry Affiliates Program.
- Local Government Vulnerability Workshops.
- Post Earthquake Clearinghouse Participation.

P_g Travel Time Tomography in the Death Valley Region from UNRSL and SCEC Data

Abu M. Asad and John N. Louie
University of Nevada, Reno

The mechanism of crustal extension in the Death Valley region continues to be a topic of debate. We investigate upper crustal heterogeneity in Death Valley and adjacent areas to have a better understanding of possible extensional mechanisms. For this, we employ simulated annealing velocity optimization, and a preconditioned LSQR algorithm. The nonlinear optimization provides us with a starting depth for the P_g refractor, the average P_g velocities, and overburden velocities we use in the linear LSQR algorithm to invert for refractor velocity heterogeneity. Our data consist of 8000 first arrival travel times from 850 events of 3.0 or greater magnitude recorded at 55 stations of the WGBSN and SCSN. We use 4 km blocks for an estimated 9 km deep P_g refractor and interpret the block delays and station delays in terms of velocity heterogeneity and refractor topography. We estimate errors by bootstrapping and resolution by synthetic checkerboard tests.

The average Pg velocity obtained is 6.015 km/s. The highest velocities in the region (6.1 km/s) occur along a north-northwest trend between the California-Nevada state line and the Death Valley-Furnace Creek fault zones, and centered on the Funeral Mountains, near reported metamorphic core complexes. The lowest velocity in the model (5.87 km/s) is found in patches along the eastern Owens Valley area.

Relocating Earthquake Clusters in Southern California

Luciana Astiz and **Peter M. Shearer**
University of California, San Diego

We use seismograms recorded by the Southern California Seismic Network (SCSN) and available through the Southern California Earthquake Center (SCEC) Data Center. Events are first relocated using existing P and S picks by applying a L1-norm, grid-search algorithm that uses station terms to account for three-dimensional velocity structure outside each aftershock region. This procedure reduces the scatter of the locations greatly (compared to the catalog hypocenters) and produces relative location accuracy comparable to master event methods. Next, we perform waveform cross-correlation of event pairs to obtain precise differential times. Since analyzing every event pair becomes impractical for large numbers of earthquakes, we apply only apply cross-correlation to nearby events. For each event we identify a target number of surrounding earthquakes by computing the Delaunay tessellation of the relocated hypocenters and finding the prescribed number of natural neighbors of each event (e.g., Sambridge et al., 1995). Prior to cross-correlation, the waveforms are low-pass filtered at 10 Hz and resampled to a uniform 100 Hz sample rate. Differential P and S travel times are obtained for those event pairs sufficiently similar to provide well-defined peaks in their cross-correlation functions. Next, we use the differential times, together with the existing travel time picks, to solve for an adjusted set of travel times that are more consistent and more complete than the original picks. Events are then relocated using the adjusted set of picks. We have applied this approach to aftershocks of the 1987 Whittier Narrows earthquake, the 1988 and 1990 Upland events and the 1986 Oceanside earthquake. For these event sequences the scatter in the locations is reduced compared to the results prior to the waveform cross-correlation. The improvement is particularly dramatic for the Oceanside sequence, a challenge for location methods since it is well outside of the network. Finally we attempt to relocate about 1500 events that occurred offshore and westward of the Los Angeles Basin in the last 15 years. These events present a double challenge since they are not located within the network and relatively few travel-time picks exists for some of these events. Preliminary relocation results indicate that waveform cross-correlations should greatly improve the relative location of these offshore events.

Sambridge, M., J. Braun and H. McQueen, (1995) Geophysical parameterization and interpolation of irregular data using natural neighbours, GJI 122, 837-857.

Site Amplifications for Southern California Network Stations from Near-Receiver-Scattered Teleseismic Coda: Techniques and Results

G. Eli Baker and **J. Bernard Minster**
University of California, San Diego

We have calculated site amplifications for 185 stations of the southern California seismic network (SCSN), using the near-receiver-scattered component of teleseismic coda, termed "diffuse" coda. We present data processing and statistical tools developed for this project and discuss the results.

We isolate the diffuse coda by first forming a beam from all SCSN records for a given event, which provides an estimate of the near-source-scattered component of the teleseismic coda. We then remove the beam from each individual record to obtain an estimate of the diffuse coda. Then, because the amplitude measurements are drawn from a heavy tailed distribution and are censored, we use two techniques that improve parameter estimates from such data. The first, the technique of robust reweighting of data based on misfit, limits bias in amplification estimates from outliers or non-Gaussian errors and improves the accuracy of the uncertainty estimates. The second technique permits the incorporation of censored data into parameter estimates through maximum likelihood estimation. Simulations and analysis of SCSN results indicate that both techniques significantly improve the accuracy of site amplification estimates as well as those of network magnitudes. The robust reweighting also has permitted identification of problems with the data that might otherwise go unnoticed, such as errors in the records of instrument calibration parameters.

We compare our results with site amplifications estimated from local S-wave coda (Su and Aki, 1995). For stations with estimates of site amplifications from both local and teleseismic coda, the results are highly correlated, except at the highest amplification sites. At those sites, which are in sedimentary basins, the local S-wave coda amplifications are up to 7.5 times greater than those from the teleseismic coda, suggesting that the two source types may have different mechanisms for generating resonance in sedimentary basins.

Su F. and K. Aki (1995), Site amplification factors in central and southern California determined from coda waves, Bull. Seis. Soc. Am., 85, 452-465.

Simultaneous Evolution of Earthquakes and Faults in a Rheologically Layered Half-Space

Yehuda Ben-Zion
University of Southern California
Vladimir Lyakhovsky and Amotz Agnon
The Hebrew University, Jerusalem, Israel

Most models of evolutionary seismicity are confined to activity along a single or a few fault systems. Notable exceptions are the works by Ward (ms., '95) and Sornette et al. (PAGEOPH, '94) which use 2D calculations of elastostatic deformations in a thin plate to simulate, respectively, long histories of regional seismicity and the development of regional faults. However, such 2D models ignore coupling of the upper seismogenic layer to a viscoelastic substrate, leading to spreading inelastic deformation zones in the ductile lower crust that transfer stress to faults in the upper brittle layer. Equally important, the above models neglect the evolution of either the geometry or the rheological properties of fault systems during deformation.

We attempt to overcome the above shortcomings by using a deformation and time-dependent damage rheology that is thermodynamically consistent. The model consists of a layered elastic/viscoelastic half-space. The seismogenic layer is treated as an elastic medium where distributed damage, modifying the elastic stiffness, evolves according to a generalized internal friction. A generalized version of the Elsasser model simulates interseismic periods, and a new 3D elastic stress transfer scheme simulates failure episodes. These developments allow us to simulate long histories of crustal deformation, and to study the simultaneous self-organization of regional earthquakes and faults.

Using the above framework we simulate seismic and aseismic deformation evolution in a model having horizontal dimensions of 500 km by 500 km, with a 15 km thick brittle upper crust. The results illustrate, for various model realizations, how initially random distribution of damage spontaneously organizes during deformation to form large crustal faults and subsidiary branches. Model output includes velocity fields, surface topography, evolving fault structures, and spatio-temporal seismicity patterns.

Southern California Permanent GPS Geodetic Array: Continuous Measurements of Regional Crustal Deformation between the 1992 Landers and 1994 Northridge Earthquakes

Y. Bock, S. Wdowinski, P. Fang, J. Zhang, J. Behr, J. Genrich, S. Williams, D. Agnew, F. Wyatt, H. Johnson, et al.
University of California, San Diego
K. Hudnut
U.S. Geological Survey, Pasadena
W. Young
Riverside County Flood Control and Water Conservation District

The southern California Permanent GPS Geodetic Array (PGGA) was established in 1990 across the Pacific-North America plate boundary in southern California to continuously monitor crustal deformation. Array data, in combination with precise satellite ephemerides derived from a global network, provide a regional anchor for determining positions with respect to a reference frame external to this diffuse plate boundary. We describe the development of the array, the components of the system developed by us to collect and analyze data every twenty-four hours, and the time series of daily positions estimated for the first ten sites in the 19-month period between the 28 June 1992 (M=7.3) Landers and 17 January 1994 (M=6.7) Northridge earthquakes. Focusing on this particular data span allows us to approximate by linear regression long-term, non-linear, postseismic deformation induced by the Landers earthquake at sites 65-100 km from the earthquake epicenter. A comparison of the post-Landers site velocities with those derived from GPS and VLBI measurements collected over nearly a decade prior to the Landers earthquake indicates changes in displacement rate at three sites which are significant at the 95% confidence level. We observe that velocity differences range between 3-5 mm/yr in magnitude and are oriented in a clockwise direction at angles between 20-45 with respect to the directions of coseismic surface displacements. These observations are consistent with a post-earthquake fault-normal contraction component that is superimposed on right-lateral slip at depth along the Landers fault trace. This is the first recorded geodetic determination of a change in regional displacement rates after a major earthquake, and suggests a region-wide non-linear viscoelastic response of the crust rather than merely a continuation of slip at depth on faults ruptured by the event. These observations may also be explained by a change of deformation across neighboring locked faults due to changes in the regional stress field. In particular, our measurements support the conclusion of others that there was a shear stress drop on the SAF fault north of the Los Angeles basin after the Landers earthquake. Our results also suggest that convergence of the Los Angeles basin with respect to the Pacific plate was reduced by about 3 mm/yr after the earthquake which is consistent with a drop in SAF-normal compressional stress across the basin prior to the Northridge earthquake.

Determining the Optimal Critical Region Before Large Earthquakes

David D. Bowman and **Charles G. Sammis**
University of Southern California

There is mounting evidence that the release of regional seismic energy may increase in the ten or so years preceding a large earthquake. This phenomenon was not recognized until recently because the active region is much larger than might be expected on the basis of an elastic dislocation model. However, such long range correlations in seismicity are expected if the large event is viewed as a critical point for the breakdown of the surrounding region. A renormalization group analysis of this critical phenomenon leads to a power-law time-to-failure equation for the energy release, and to log periodic fluctuation about this power law if the renormalization group is discrete. Discrete renormalization can result, for example, from a discrete fractal hierarchy in the regional fault network. Any attempt to apply the time-to-failure equation and look for log-periodic fluctuations in real seismicity data must face the question: how does one choose the size of the region to be analyzed? We present here a quantitative procedure which answers to this question. The precursory seismicity in a circle of radius r centered on the mainshock is fit to both a linear and a power law time-to-failure equation and the root-mean-square (RMS) deviation of the data from both fits is calculated. The ratio Ω of the RMS deviation for the power-law fit to the RMS deviation for the linear fit is calculated. When this procedure is applied to a range of region radii r, the size of the critical region is determined by the minimum value of Ω, since this value minimizes the RMS error of the power law relative to the linear fit. The width of this minimum also gives a measure of the uncertainty in the size of the optimal region. When we apply this method to earthquakes which span a range of magnitudes, we find that the area of the critical region is linearly proportional to the magnitude.

CRUSTAL IMAGING IN SOUTHERN CALIFORNIA USING THE NORTHRIDGE AND SIERRA MADRE EARTHQUAKE SEQUENCES

Sergio Chavez-Perez and **John N. Louie**
University of Nevada, Reno

One way to refine the alternative thick- and thin-skinned hypotheses for blind-thrust faulting in southern California is to use aftershock recordings for crustal imaging. We devise a definitive test that images fault structure using three-dimensional, wide-angle prestack Kirchhoff migration. We achieve this with the use of aftershock traces recorded by the short-period vertical stations of the Southern California Seismic Network. This work complements seismicity and focal mechanism work by imaging reflectivity cross sections and volumes rather than having to associate events with faults. Further, it can image below the seismogenic zone. We demonstrate that these images show reflective structures, and that we can use clipped high-gain seismograms as sign-bit data to yield valid geometric imaging. Work with data from the 1994 Northridge earthquake sequence produce images of the Moho, and possibly structures in the mid-crust related to the proposed blind thrust fault systems in the area, including the geometry of the fault that generated the main event. The images test the existence and configuration of thrust ramps and detachments proposed from balanced-section reconstructions of shallow-crustal profiles and borehole data. In addition, we will show initial images for the crust below the 1991 Sierra Madre earthquake sequence. We will correlate our images with a prominent lower crustal reflective zone observed beneath most of the San Gabriel Mountains by LARSE (Los Angeles Region Seismic Experiment) Line 1.

LOCAL SITE CHARACTERISTICS ON GROUND MOTION ACCELERATION DURING THE 1994 NORTHRIDGE EARTHQUAKE

Byau-Heng Chin and **Keiiti Aki**
University of Southern California

The goal of this study is to investigate the local site response during the 1994 Northridge earthquake. First, the ground motion prediction method was validated by simulating 27 rock site stations. The predicted peak ground acceleration shows in good agreement with the observed for the whole distance range. Then, we calculated the site amplification factor by comparing the observed motion at the surface of soil sites with the predicted basement motion. A new surface versus basement PGA curves derived from a site located in downtown Los Angeles has been developed using 1-D nonlinear analysis. The data points are spread between the predicted curves for the linear and non-linear models. Finally, a method for correcting the amplification factor for this non-linear effect has been applied successfully using the strong motion data from the 1994 Northridge earthquake.

Elastodynamic Simulations of Earthquake Sequences and Slip Complexity on an Isolated Fault Segment in a 3D Solid

Alain Cochard and **James R. Rice**
Harvard University

We study earthquake sequences using numerical simulations of a planar and rectangular fault segment, with spatially homogeneous friction properties, embedded in a 3D elastic solid. The solid is slowly loaded and slip is confined to the segment by strong barriers at its borders. The purpose is to find what is the preferred rupture mode for individual events (enlarging crack vs. self-healing pulse) and to find what is the statistical size distribution for all the events (characteristic earthquakes vs. G-R), depending on the constitutive law that applies on the fault plane.

The constitutive law used agrees with lab studies at low slip rate, i.e., rate/state with logarithmic dependence, but extrapolates such studies with a much stronger velocity dependence at typical seismic slip rate (where no lab data exist), i.e., in the form $1/(1+V/V_{weak})$. Such is done because previous favored with such strongly velocity weakening behavior; see Cochard and Madariaga (*JGR*, 1996, in press) and Zheng and Rice (this meeting) for 2D studies.

The elastodynamic model used for the surrounding medium is a 3D scalar model, which is simplified compared to real vectorial elastodynamics in that displacement occurs in only one direction and there is only one wave speed. The methodology adopts the spectral formulation, but in a way that the artificial periodicity of the rupture event inherent to earlier implementations has been rigorously eliminated (Cochard and Rice, *J. Mech. Phys. Solids*, submitted).

Crustal Deformation Velocity Map of Southern California

Crustal Deformation Working Group
Southern California Earthquake Center
Homepage: http://scec.ess.ucla.edu/velmap/welcome.shtml

We use GPS data from experiments TREX 86-91, STRC 88-95, HPGN 91-94, LABS 87-93, Inter-county 93, Ventura Basin 92-93, Santa Maria Basin 90 and 94, Santa Barbara Channel 91, Landers Post-seismic Joint Survey 92, Gorman 92, Mojave Desert 94-95, and EDM data from USGS 70-92 to estimate the aseismic crustal velocity over a broad area of Southern California from 31.5N to 36.5N.

GPS daily solutions are obtained using the GAMIT software and combined together using the GLOBK and JPLS (being developed by D. Dong) software to solve for station positions, velocities, and coseismic displacements. Velocities of a subset of fiducial sites are constrained using GSFC VLBI solution GLB1014. Velocities at Vandenberg, JPL, Mojave, and Pinon from the PGGA are used as constraint as well. A priori coseismic displacement constraints for Joshua Tree, Landers, and Northridge earthquakes are obtained from independent coseismic studies.

The EDM data were adjusted with loose constraints and then combined with the GPS velocities using JPLS. 287 independent velocities with horizontal uncertainties ranging from 1 to 4 mm/yr are obtained.

Our preliminary result shows that the far-field velocities across the San Andreas and its associated major faults are about 36 mm/yr at the Carrizo Plain, 40 mm/yr at the Mojave section, and 45 mm/yr at the Coachella Valley. More than 10 mm/yr postseismic deformation, with 2-3 years of time span following the Landers earthquake, is found in the central Mojave desert.

TECTONIC GEOMORPHOLOGY OF LA MESA, SANTA BARBARA FOLD BELT, CALIFORNIA

Marcy B. Davis, SCEC Summer Intern
University of California, Santa Barbara

La Mesa forms a prominent topographic high along the Santa Barbara coastal plain. Geomorphic mapping identifies five emergent marine terraces on La Mesa. A minimum age for the youngest emergent terrace has been determined using U-Th series analysis on a solitary coral (*Balonphyllia elegans*) at 70 +/- 2ka (Gurrola, Chen, and Keller, 1996, unpub. data). This date is interpreted as 83ka (oxygen isotope stage 5a), the next older sea level highstand. An age of 83ka, a shoreline angle elevation of 30 m., and paleosealevel at approximately -20 m., yields a calculated uplift rate of 0.6 m/ka. Assuming a constant rate of uplift, ages of older emergent marine terraces are 105, 118, 123, and 200ka, respectively. Folding of emergent paleoshoreline angles suggests that the Lavigia fault may be a buried reverse fault through central La Mesa, resulting in a shallow fault-propagation fold. The Mesa fault is a high-angle reverse fault with a simple block faulting component. The Mesa and Lavigia faults, which strike northwest-southeast, may be considered potentially active. Calculated vertical uplift rates and understanding styles of deformation for La Mesa will provide a higher resolution assessment of the seismic hazards for the Santa Barbara area.

3D GROUND MOTION SIMULATIONS USING RECURSIVE GRIDDING

Steven M. Day, Harold Magistrale and **Keith L. McLaughlin***
San Diego State University
*Maxwell Technologies

We have used a 3D linear finite difference method based on recursive gridding to simulate low-frequency ground motion from large earthquakes in the Los Angeles region. The recursive gridding increases feasible bandwidth in the presence of the wide range of seismic velocities that our realistic Los Angeles basin model contains. We are in the process of constructing a larger model that includes the Ventura basin, and the Chino, San Bernardino, and Santa Clarita Valleys. Several suites of Northridge earthquake calculations were performed including a kinematic mainshock source, a point source at the distributed mainshock source centroid, and point source aftershocks. A 128 m resolution model of the San Fernando Valley was used to make calculations with bandwidth to 0.8 Hz. A larger 256 m resolution model of the greater LA Basin was used to make several calculations with bandwidth to 0.4 Hz and one calculation with 128 m resolution and bandwidth to 0.8 Hz. The 3D simulations are compared with layered model calculations. Interesting simulated wave propagation is observed including generation of basin waves and focusing/defocusing of the direct waves by deep basin structures.

Stress Evolution and Earthquake Triggering on Fast and Slow Moving Faults in Southern California

Jishu Deng and **Lynn R. Sykes**
Lamont-Doherty Earth Observatory of Columbia University

The Coulomb stress (DCFF) evolutionary history for the southern San Andreas fault and several of its neighboring slow-moving faults is calculated using both elastic and visco-elastic models. The stress accumulation rate differs significantly from segment to segment along the southern San Andreas fault. Most parts of the Mojave segment from Mill Potrero to Pallet Creek will continue to be in a stress shadow zone created by the 1812 Wrightwood and 1857 Fort Tejon earthquakes for at least several decades. One or two segments between Parkfield and Mill Potrero are currently positive stress zones depending upon the slip assumed for the 1857 shock. They are possible sites of moderate to large future earthquakes of M~7. The stress along the Coachella Valley segment including Indio and Bombay Beach until 2025 ranges from 7 to 10 Mpa higher than the starting level before the 1812 Wrightwood earthquake. Thus, a great earthquake rupturing both the San Bernardino and Coachella Valley segments could possibly occur in the next few decades. The history of DCFF for two slow moving right-lateral strike-slip fault zones, the Newport-Inglewood fault and the series of faults that ruptured in the 1992 Landers earthquake, shows that the overall long-term interseismic stress field near a slow-moving fault is a combination of a very slow increase associated with neighboring fast-moving faults. During the relatively long cycle of Landers earthquakes, the stress field near its rupture zone is modulated by the occurrence of more frequent great earthquakes and subsequent stress buildup along the southern San Andreas fault. Just before the 1992 Landers shock the DCFF near its epicenter reached values as high as 0.5-0.8 Mpa above the value before the occurrence of the great 1812 Wrightwood earthquake. The cumulative DCFF along the Newport-Inglewood fault from 1812 to 1933 just before the Long Beach earthquake increased to positive values between 0.2 and 0.5 Mpa along most of what was to become its aftershock zone. Since the long-term rate of the Newport-Inglewood fault is very slow, this amount of positive change in DCFF was likely very significant in advancing the time of occurrence of the 1933 Long Beach earthquake. We will examine how much the segment of that fault to the north of the 1933 rupture zone has moved toward failure.

Evidence for Probable Moderate-Sized (Mw 6.5-7.0) Paleoearthquakes on the Cucamonga Fault, Day Canyon, Northwestern Los Angeles Metropolitan Region, California

James F. Dolan
University of Southern California
F. Jordan and **G. Rasmussen,** Gary Rasmussen and Associates
D. Stevens, California Institute of Technology
W. Reeder, County of San Bernardino, Public Works Group
L. M. McFadden, University of New Mexico

One of the most pressing questions facing seismic hazard planners in the metropolitan Los Angeles region concerns the size and frequency of earthquakes along the 90 km-long Sierra Madre-Cucamonga fault system. A 35 m-long, 9 m-deep trench excavated across the most prominent of three major scarps on Day Canyon (Strand C of Morton and Matti, 1987) revealed two colluvial wedges along the main, 25-30°N-dipping fault zone. Each of the wedges resulted from ~3 m of thrust motion, placing an upper bound on the maximum displacement during the past few earthquakes. However, geometric relationships in the younger colluvial wedge require that it developed during a minimum of three events. The most recent earthquake caused ~80 cm of slip. We estimate dip slip rates of ~2.5 to 5 mm/yr for strand C, and ~1 to 2 mm/yr for strand B. These data do not preclude the occurrence of very large earthquakes in which the Cucamonga fault might rupture together with adjacent faults (e. g., Sierra Madre) but they do suggest that at least the past several Cucamonga fault earthquakes were only moderate to moderately large in size. If the 1-2 m average slip/event we measure is representative of the entire rupture plane, then the past several events have probably been in the Mw ~6.5-7.0 range, and have most likely involved rupture of the Cucamonga fault by itself.

Geodetically Derived Horizontal Velocity Field in Southern California

Danan Dong
Jet Propulsion Laboratory

64 GPS campaign data sets from 1986 to 1995 have been combined to obtain the crustal horizontal velocity field in southern California. The velocity solutions at about 180 sites with formal uncertainties less than 10 mm/yr. Among these sites, about 130 sites have velocity solutions with formal uncertainties less than 3 mm/yr. Coseismic site displacements have been estimated implicitly. Due to the sampling limit (only a few campaign data after the earthquakes), the postseismic deformation has been modeled only for a few near-field sites, which is equivalent to considering only short spatial wavelength effects. This GPS derived velocity solution is combined with USGS EDM data to obtain denser velocity field. Our result will be compared with previous GPS only, VLBI only and EDM only velocity solutions.

Interseismic Surface Deformation Signatures from Blind Thrust Faults

Andrea Donnellan
Jet Propulsion Laboratory
Gregory Lyzenga
Harvey Mudd College

Precise geodetic measurements from GPS networks and other techniques provide a means to characterize crustal deformation caused by activity on hidden faults. Blind thrust faults beneath the greater Los Angeles region and bordering the Transverse Ranges pose a seismic risk and may produce discernible interseismic deformation signatures. To examine these patterns, synthetic deformation profiles have been produced assuming different rheological structures for the crust. Specifically, viscoelastic deformation is allowed to occur between the times of earthquakes in the crust, in one of two ductile regions of the crust.

Ductile lower crustal models assume that relaxation on time scales of years to centuries relieves stress at the base of the seismogenic zone (~20 km). In contrast, ductile uppermost crustal models incorporate relatively incompetent sediments in the upper ~5 km, relaxing on time scales of months to decades. The signatures of these distinct mechanisms are computed using finite element methods. Also, the synthetic deformation patterns are inverted for equivalent elastic dislocation sources, as a means of further quantifying the effect on postseismic geodetic measurements and their ability to be distinguished from fault afterslip. The applications of this modeling to the Northridge postseismic data set is discussed.

METHODOLOGY FOR THE UTILIZATION OF THE SCEC GEOTECHNICAL DATABASE TO ASSESS THE NONLINEAR SITE RESPONSE

Macan Doroudian and **Mladen Vucetic**
University of California, Los Angeles

To advance the understanding of the effects of local geotechnical and geologic site conditions on the character and magnitude of ground shaking and associated damages to structures, SCEC supported the development of a 3-dimensional database of Los Angeles. This database consists of about 1000 digitized geotechnical boring logs created using a GIS software called "Techbase". The database will be used to approximate the stratification and engineering soil parameters at the locations of the boring logs needed for 1-dimensional nonlinear site response analyses. Within the GIS system for each boring log this information will be automatically generated by "Techbase", and then used as the input for the nonlinear site response analysis of the soil profile pertaining to that particular boring log. In this way, the nonlinear site response analyses for many boring logs within an area of similar base rock shaking could be conducted at the same time, using the same base rock excitation input. From the outputs of the analyses the maps of ground shaking, seismic pore water pressures, predominant periods of ground surface motion, etc., will be produced. The poster will display a description of the geotechnical database, nonlinear site response model, charts of cyclic soil behavior used to transform the data from the database into the input parameters for the nonlinear analyses, and the methodology how to link these components within the existing GIS.

Presence of Aseismic Deformation in the Upper to Middle Crust of the Western Transverse Ranges, Southern California

E.M. Duebendorfer, Northern Arizona University
J. Vermilye, Vassar College
P.A Geiser, CogniSeis Development Corporation
T. L. Davis, Davis and Namson Consulting Geologists

Recent SCEC studies show that deformation rates determined by geologic and geodesic studies are far in excess of that which can be accounted for by historical seismicity and thus, a deficit of moderate and/or large earthquakes exists in southern California. While possible, this conclusion is not unique because the contribution of aseismic deformation to the regional strain was not considered. We have conducted field and microstructural investigations and found that aseismic deformational mechanisms may have played an important role in regional shortening in southern California during the late Neogene. We sampled rocks recently buried from 1 to nearly 14 km in four cross-strike transects to evaluate the presence of aseismic processes. Experimental and empirical studies show that at these depths and corresponding temperatures, pressure solution is expected to be an active deformational mechanism. Our field and microstructural observations show that pressure solution was active and may have made a significant contribution to permanent strain. Effects of pressure solution appear to be related to temperature increase with depth of burial. This mechanism may accommodate deformation during the relatively slow strain rate periods between high strain-rate seismic events. Future work will quantify volume loss due to pressure solution which may reduce or possibly eliminate the proposed seismic deficiency.

Strong Basin-Edge Induced Waves in the Coachella Valley: Observations and Modeling

E. H. Field
University of Southern California

Strong basin-edge induced waves were observed in the Coachella Valley near Palm Springs, California during the Landers/Big-Bear aftershock sequence. These observations provide an opportunity to test theoretical simulations. If satisfactory agreement can be obtained for these aftershocks, then the important question of how variable the response is with respect to other source locations can be explored theoretically.

The only pre-existing information on the local basin structure comes from gravity data. Therefore, much effort has gone into constructing a two-dimensional basin model using the aftershock data to provide additional constraints. These come from: observed resonant frequencies; observed P- to S-wave conversions; and simple ray tracing. After outlining how each of these help constrain the physical model, the results of 2.5-D finite element modeling will be presented.

Earthquake Recurrence Studies of the Tujunga Segment of the 1971 San Fernando Rupture

T. E. Fumal, A. B. Davies, T. Dawson, W. T. Frost, J. O'Donnell, G. Sega and D. P. Schwartz
U. S. Geological Survey, Menlo Park

The 1992 Northridge earthquake (M 6.7) sparked renewed interest in the activity of the zone of thrust faulting along the south margin of the San Gabriel Mountains. After the 1971 San Fernando earthquake, M. Bonilla, USGS, excavated several trenches across the rupture, including those at Oak Hill and Bartholomaus Ranch and suggested recurrent slip and a prior event about 200 years ago.

We excavated two trenches at Bartholomaus Ranch parallel to and about 2-3m on either side of Bonilla's 1971 trench A. In our east trench net slip on the 1971 traces is 48cm with a vertical separation of 20 cm. In this trench the upper contact of a distinctive older colluvial deposit is displaced vertically about 52 cm, more than twice the 1971 vertical slip. In addition, several traces that displace this contact are overlain by unfaulted deposits, providing evidence for the penultimate event. Radiocarbon dating of detrital charcoal samples suggests that the penultimate event occurred about 300-400 years ago.

We also excavated a 6-m deep pit across the 1971 rupture at Middle Ranch, about 1.7km to the east. The stratigraphy at this site consists of massive, fine-grained colluvium overlying moderately well-bedded sandy and gravelly fluvial deposits. Displacements for the past three events are about 70cm, 90cm, and 65cm. Radiocarbon dating of detrital charcoal in the colluvial layer suggests that the penultimate event at this site occurred prior to 350 years ago.

Restraining Bend Along the Palos Verdes Fault, Offshore Southern California

Robert D. Francis, CSU Long Beach
Mark R. Legg, ACTA, SDSU
David R. Sigurdson, CSU Dominguez Hills
Peter J. Fischer, CSU Northridge

About 13 km south of Los Angeles Harbor lies a restraining bend, 1-2 km long, in the Palos Verdes fault. We mapped the fault from the harbor entrance to 15 km offshore using a dense grid of high-resolution, single-channel, seismic reflection profiles, augmented by multi-channel seismic data for deeper imaging. The restraining bend occurs about 1-km from the southern end of a 13-km long fault segment that is terminated by a 200-m right (releasing) offset. At the bend, the fault curves sharply to the west for about 300 m, then assumes a more northerly strike for 1-2 km north of the bend before resuming its more typical N35°W trend. In the upper 200 m below the seafloor, the near-vertical fault juxtaposes northeast-dipping Pliocene and older sediments on the southwest side against sub-horizontal Pleistocene and Holocene sediments on the northeast side. Restraining bends are common along the fault, and include large bends at Lasuen Knoll and the Palos Verdes Hills. Few historical earthquakes in the bend area may imply that the fault is locked, awaiting the occurrence of a moderate to large earthquake along this fault segment. Holocene deformation is implied by a 1-4 m high seafloor bulge associated with the southwest flank of the bend.

A Block-Fault Model Based on the SCEC Crustal Deformation Velocity Map and its Implication for Seismic Hazards

X. B. Ge, Z-K. Shen and **D. D. Jackson**
University of California, Los Angeles

The aseismic crustal deformation field throughout California is calculated based on the SCEC Crustal Deformation Velocity Map (Sung, et al) and other geodetic data. We divide California into 19 blocks bounded by 131 fault segments. We simulate the crustal deformation by a combination of rigid block motion and elastic deformation generated by uniform dislocations on each of the fault segments. On the surface of the Earth, dislocations offset the relative block motion so that the displacements are continuous across the block boundaries. There are 12 exceptions where creep is observed and therefore allowed in the model. A Bayesian inversion method is used to estimate the model parameters with prior constraints determined by information from other sources. The model fits the data well, indicating that the new GPS data are consistent with the traditional geodetic data. The dominant tectonic feature in California is the dextral motion along the San Andreas fault. The highest slip rate is about 34 mm per year on the Carrizo Plain segment of the San Andreas. The slip rate on the Mojave and Coachella segments of the San Andreas are 27 and 24 mm per year respectively. The results are generally compatible with the SCEC Phase II report based on geological and paleo-seismological data covering the past 100 thousand years. The net block motion across California is 53 mm per year. The Western Transverse Ranges are found to rotate clockwise at a rate of 3 degrees per million year.

Three Dimensional Seismo-Tectonic Imaging in the California Transverse Ranges

Peter Geiser
CogniSeis Development (Current Address: LDEO, Palisades, NY)
Nano Seeber
Lamont-Doherty Earth Observatory

Deformation processes, create a pattern of unrecoverable infinitesimal strain, while structure, is the manifestation of finite strain. The two are distinct but related elements of tectonics. Structure which can be directly measured, results from deformation processes operating over geologic time. Deformation processes are geologically instantaneous and generally not directly observable. Thus data pertinent to structure and to deformation processes tend to belong to distinct classes requiring different techniques. For example, classical structural data provide information on the structural geometry and total accumulated deformation, but not on the current pattern of deformation. In contrast earthquakes provide a unique direct view of instantaneous deformation. This view, however, is partial; earthquakes illuminate only elements which deform seismogenically and only those which are active during the data sample.

A consequence of the foregoing is that the observational basis for tectonic interpretations is either geometric/kinematic or process oriented, but rarely an effective combination of both. Thus, tectonic imaging refers to techniques to model structure using classical structural data, (e.g., Suppe 1983; Davis et al, 1989; Geiser, 1988) whereas earthquakes provide a unique direct view of instantaneous deformation. In contrast, seismo-tectonics is the study of the current instantaneous deformation regime reflected by earthquake data in the context of the finite geometry and kinematics of the tectonic image.

The relationship between seismogenesis, as an instantaneous incremental strain and structure as finite strain is the main focus of this study. We introduce 3D Seismo-Tectonic Imaging (STI), as a new approach for tectonic analysis and for investigating the role of structure in seismogenesis. STI combines 3D tectonic imaging and tectonic interpretation of earthquake focal-mechanisms to:

- map active structures and to resolve what portions or elements of the structure are seismogenic.
- Act as an independent check on the structural interpretation of the tectonic imaging process.

We apply STI to a three-dimensional transect through the Northridge area of the Transverse Ranges where recent seismic sequences provide hundreds of reliable focal mechanisms of small earthquakes, and where a better understanding of structure and seismogenesis is crucial for quantifying earthquake hazard. This first test of STI addresses the following questions:

- Is the seismicity consistent with patterns of finite strain predicted by rock deformation models?
- Which elements in the structure are seismogenic?
- Do earthquakes and structure provide complementary data for resolving rock deformation patterns? Can one be used to test the other where they overlap?

The results demonstrate that STI has more resolving power than methods relying on either structural or earthquake data alone and that earthquakes are generated on faults recognized from structural data, but also within volumes with diffused strain bounded by these faults. Because the two data sets (structural and earthquake) are independent, initial analysis of the data is done "blind", i.e. the earthquake and structural analysis are done separately and then input to a 3D tectonic imaging program (Geosec 3D) where the results are combined to form a coherent seismo-tectonic image.

Developing a Science Education Module for the Southern California Integrated GPS Network

Maggi Glasscoe, SCEC Summer Intern, USC
Julie Pappas, SCEC Education Intern, USC
Andrea Donnellan, Jet Propulsion Laboratory

By utilizing data collected by the Global Positioning System (GPS) array in the Los Angeles Basin, we will develop a science education module for the Southern California Integrated GPS Network (SCIGN). The module would make use of the World Wide Web to post activities that relate to the use of the GPS system in geodetic research and in evaluating seismic hazards. By constructing activities targeted to high school aged and older students, we hope that we can further understanding of active tectonics as it relates to seismicity in the Los Angeles Basin and the use of GPS to predict seismic risk.

NEOTECTONICS AND EARTHQUAKE POTENTIAL OF THE SAN JOAQUIN HILLS, ORANGE COUNTY, CALIFORNIA

Lisa Grant
Chapman University
Eldon Gath and **Roz Munro**
Leighton and Associates, Irvine, CA
(in collaboration with **Glen Roquemore**, Irvine Valley College)

The structure and geomorphology of the northern San Joaquin Hills (SJH) suggests that they are a northwest trending, northwest plunging anticline that may be underlain by a blind thrust. A suite of eight emergent marine terraces is present along the coastal margin, wrapping inland through the Newport Back Bay, an antecedent but abandoned course of the Santa Ana River. The ages of the terraces are constrained by amino acid racemization and zoogeographic correlations on the 1st, 2nd, and 4th platforms (Barrie et al., 1992).

Correlation of the terraces with sea level highstands suggests an uplift rate of 0.25 mm/yr from 0.08-1Ma. We are compiling additional data on the locations, platform geometries, ages, and shoreline angles of terraces around the northern nose of the SJH to map the pattern of Quaternary deformation. We are also compiling data on the locations of terrace deposits on the northeastern and eastern margins of the SJH, and additional mapping south to Laguna Beach. Preliminary data indicate that a late Pleistocene terrace platform on the north side of Newport Bay is antiformally deformed. In addition, a poorly documented 1950s survey of Back Bay, prior to road construction, reported antiformal deformation of Holocene deposits (Stevenson and Emery, 1958), suggesting that the deformation is ongoing.

ROLE OF CROSS-FAULTS AS TEARS IN THRUST RAMPS IN THE VENTURA AND SANTA BARBARA FOLD BELTS, CALIFORNIA

Larry D. Gurrola and **Marc Kamerling**
University of California, Santa Barbara

Moderate-large earthquake ruptures in fold and thrust belts, such as the 1971 San Fernando, the 1978 Santa Barbara, and the 1994 Northridge earthquakes commonly originate and terminate laterally along high-angle, strike-slip faults, generally called tear faults. Tear faults transfer strain deformation along steps in thrust ramps. High-angle, strike-slip, cross-faults that segment the principal east-west striking, thrust faults in the onshore and offshore Ventura and Santa Barbara fold belts (VFB and SBFB) are inferred to be tear faults. Although they are not well-expressed, evidence for their presence include subtle surface lineations, discontinuities of east-west structures, as well as geomorphic expression and seismicity. In the SBFB, cross-faults that may behave as tears include the Goleta Point, the Fernald Point, and the Rincon Point faults.

The inferred locations of two such north-south striking tear faults coincide with the west and east boundaries of the 1978 Santa Barbara earthquake presumed to have ruptured offshore, along a east-west striking, north-dipping thrust. The 1968 Santa Barbara earthquake may have occurred on a subsea tear fault.

Tear faults in the SBFB may be seismic sources and form termination boundaries on thrust ramps providing additional insight on potential rupture length. Clearly, further investigation in the role of cross-faults as tears is required to understand earthquake hazards in the VFB and SBFB.

SEGMENTATION OF THE MISSION RIDGE FAULT SYSTEM BASED ON GEOMORPHIC AND STRUCTURAL EXPRESSION, SANTA BARBARA FOLD BELT, CA

Larry D. Gurrola, Roger C. Slayman*, Ross D. Hartleb, Edward A. Keller
University of California, Santa Barbara
*Fugro West

The Mission Ridge Fault System (MRFS) is a 70 km long, east-west trending reverse fault system in the Santa Barbara and Ventura Fold Belts and is subdivided, from west to east, into the More Ranch, Mission Ridge, and Arroyo Parida-Santa Ana segments. These principal segments are defined by structural and geomorphic characteristics and are bounded by northeast and northwest trending cross-faults.

The More Ranch fault is further subdivided into west and east segments and coincides with the northeast-trending, Goleta Point fault. Geomorphology of this left-stepping, boundary includes complex cross-faulting and local down warping of the Goleta Slough. The More Ranch-Mission Ridge segment boundary is expressed as a left-bend and truncates the northwest-trending San Jose and Mesa faults.

The Mission Ridge-Arroyo Parida segment boundary is characterized by a left-step and coincides with the northeast-trending Fernald Point fault. Structural and geomorphic expression of this boundary consists of truncated folds and landforms. The Arroyo Parida fault may be subdivided into west and east segments based on stream length-gradient indices and vertical stratigraphic separation. The Santa Ana segment is delineated from the Arroyo Parida fault by hanging wall deformation and geomorphic expression .

Identification of structural and geomorphic segment boundaries along the MRFS allows for increased understanding of potential fault rupture lengths and corresponding magnitudes of earthquakes. Ultimately, the identification and role of segment boundaries will refine our understanding of the earthquake hazards of the Santa Barbara Fold Belt.

MID AND LOWER-CRUSTAL STRUCTURE BENEATH THE SAN GABRIEL MOUNTAINS, CA. (LARSE)

Katrin Hafner and **Robert W. Clayton**
California Institute of Technology

Analyses of explosion data from the 1994 (LARSE) reveal several features in the crust under the San Gabriel Mountains: 1) contrasting upper and lower regions of the crust as indicated by a well defined P_g phase; 2) a broad reflector at ~7 seconds; 3) reflections related to frontal fault systems, and possibly from southward dipping faults at the northern end of the mountains; and 4) a Moho reflection at the northern end of the mountains extending into the Mojave Desert Region.

Analyses of the P_g arrivals show substantial travel time variations in the upper crust related to the Los Angeles Basin and the San Gabriel Mountains. Travel time residual values for the refracted mid-crustal P_g phase are significantly less than values needed to correct for the surface topography. This suggests that the San Gabriel Mountains are underlain by a faster velocity material.

In a stack of common midpoint (CMP) data at standard crustal velocities, PmP phases (reflections off of the Moho) show a reflector at 11 seconds (34 km depth) in the Mojave Desert Region. This reflector dips southward underneath the mountains for approximately 30 km to 16 seconds (~50km depth). This depth could compensate for the topographic variations in the San Gabriel Mountains. Although migration and refined velocity estimates could decrease the apparent depth of the dipping section, this depth is still considerably deeper than the 30 km depths inferred from previous tomographic studies in the area. It appears that a significant portion, but perhaps not all, of the compensation is in the form of an Airy root.

SCEC DATA CENTER ACTIVITIES - CURRENT AND FUTURE

Katrin Hafner and **Robert W. Clayton**
California Institute of Technology

As the Internet has become more widely available, access to the SCEC Data Center has steadily increased. Users access earthquake information and seismic data from the data center via "finger quake", "anonymous ftp", individual research accounts, and the WWW. Results from a recent questionnaire suggest that all of these interfaces have been successful with the research community. Future developments of the WWW interfaces should allow the users to more interactively search and retrieve data from seismicity and phase catalogs, as well as station databases.

In the past year the data center (in conjunction with Education) has developed and made available interactive seismicity and fault maps, animations of aftershock sequences and rupture models, and descriptions and preliminary results of LARSE activities. A coordinated effort with Northern California is currently underway to provide interactive seismicity maps for recent earthquake activity in California and Nevada. Development of a WWW interface allowing users to search and retrieve hypocenter and phase information from the SCECDC is also in progress.

Results from the questionnaire suggest that, with a few exceptions, the data center is providing data in the desired data formats. The waveform archive is being accessed on a fairly continuous basis, although mostly for events larger than magnitude 2.5. Providing all of the data online at all times has made a difference in the nature of possible research projects utilizing the data archive. However with current storage limitations and increased data flow, this degree of availability may need to be modified.

A Quantitative Investigation of the Static Stress Change Model of Earthquake Triggering for Aftershock Sequences

Jeanne Hardebeck and **Julie J. Norris**
California Institute of Technology

To explore how well static stress change explains the triggering of aftershock sequences, we quantitatively compare the number of events consistent with static stress triggering in a recorded aftershock sequence with those of synthetic random aftershock sequences.

We model the 1994 Northridge earthquake as dislocations in an elastic half-space and calculate the change in the stress tensor at aftershock locations. We compute the Coulomb stress change on each nodal plane, and find the percent of aftershocks consistent with static stress triggering, i.e. at least one nodal plane with positive Coulomb stress change. The same percentage is computed for synthetic random aftershock sequences.

Approximately 72% of the Northridge aftershocks are consistent with triggering, compared to a mean of 74% for the synthetic sequences. Only for events more than about 6 km from the mainshock fault plane is the percent of real aftershocks consistent with triggering generally at least two standard deviations greater than the mean percent for random aftershock sequences. For events closer than this, the real aftershocks are generally indistinguishable from random sequences. The calculated Coulomb stress increases appear large enough to be significant, averaging over 0.2 bars 15 km from the fault plane.

What do Low-Velocity Zones do to Spontaneously Propagating Earthquakes?

Ruth A Harris
United States Geological Survey
Steven M. Day
San Diego State University

We used a 2D finite-difference code that simulates spontaneously propagating (unforced) earthquakes to assess how a laterally heterogeneous crust affects earthquake dynamics. We simulated earthquakes rupturing fault-bisected and fault-bounded low-velocity zones (LVZ's), with a range of velocity contrasts, and of LVZ widths.

For the narrowest fault-bisected LVZ, the rupture velocity of the simulated earthquake is primarily controlled by the shear-wave velocity of the country rock. As the LVZ widens, it gradually controls the rupture velocity until the earthquake's rupture speed is determined by the LVZ.

For finite-width fault bounded (on 1 side) LVZ's, the slip-velocity, rupture velocity, and normal stress are all changed from that of an earthquake in a homogeneous material. The LVZ causes the slip-velocity and normal stress to interact. Both the rupture velocity and pulse shapes are perturbed from those of simple shear crack models.

When the fault occurs at the LVZ interface, the normal stress is reduced, but only up to 20%, for a 30% velocity contrast and 100 bar stress drop. This normal stress reduction alone is unlikely to reduce the frictional heating and does not come close to opening the fault.

DIGITAL FAULT MAP AND DATABASE FOR SOUTHERN CALIFORNIA

Suzanne Hecker, Katherine J. Kendrick, Daniel J. Ponti, John C. Hamilton
U.S. Geological Survey, Menlo Park

The U.S. Geological Survey is compiling a digital map and database of geologic information pertaining to the location, rate, recency, and recurrence of known active faults in the Los Angeles and Long Beach 60' x 30' 100,000-scale map sheets. The database, designed with input from potential end-users, provides information on earthquake sources necessary to define and communicate regional seismic hazards and to focus future research. Because deficiencies in knowledge regarding seismic sources significantly hinders hazard evaluation, we emphasize assessment of how well the geologic data constrain estimates of fault activity. Although previous compilations assign quality ratings to parameters that describe fault activity, we now have standardized descriptions of the sources of uncertainty and their likely impact on the reliability of reported values. This approach renders more systematic and explicit reliability ratings. The current emphasis among evaluators of seismic hazards on deriving consensus deformation rates makes objective evaluation of data quality especially important.

The digital database combines spatial and descriptive information in a relational format. A map of faults and study sites displayed at 1:100,000 scale is linked to data files containing (1) location and map-scale information and (2) fault-parameter information both specific to individual studies and summarized for entire faults or fault segments. The database is designed to allow information to be searched, sorted, or displayed, either interactively via the World Wide Web or on a local personal computer.

Geodetic Rate Change Observed at JPLM after the Northridge Earthquake

Michael Heflin, Deborah Dauger, Andrea Donnellan, Ken Hurst, David Jefferson, Gregory Lyzenga, Michael Watkins, Frank Webb,
and **James Zumberge**
Jet Propulsion Laboratory

Continuous GPS measurements spanning more than five years from 1991 through 1996 indicate a significant rate change at JPLM after the Northridge earthquake. The east component shows integrated excess motion of 35 +- 4 mm after estimates of the pre-quake rate and co-seismic offset have been subtracted. The excess motion is observed on baselines from JPLM to GOLD and other global network sites, ruling out the possibility of a reference frame error. A local survey from JPLM to B238 did not change, ruling out local effects at the JPLM monument such as slumping of the hillside. The direction and magnitude of excess motion are not consistent with additional slip on the fault with ruptured during the Northridge earthquake. These observations, combined with the fact that JPLM is located directly on the escarpment of the Sierra Madre fault system, suggest that some process other than simple post-seismic response occurred following the Northridge earthquake.

CAN OXYGEN ISOTOPE EVALUATION BE USED TO CORRELATE UPLIFTED MARINE TERRACES?

Ingrid Hendy, Larry D. Gurrola, Edward A. Keller, and **James H. Chen***
University of California, Santa Barbara
*California Institute of Technology

Two emergent wave-cut platforms (marine terraces) in the Santa Barbara Fold Belt have been dated by U-Th series of solitary corals "Balanophyllia elegans" at approximately 47ka and 70ka. Attempts to obtain corals from other terrace fossil sites of unknown age have not been successful due to the rare occurrence of those organisms. However, those sites do contain fossils, mostly various mollusca, that have been identified and sampled. Stable oxygen isotopes from shells of several species of mollusca suggest that the 47ka terrace (isotope stage 3) has a distinctly different isotopic signature from the 70ka terrace (isotope stage 5). Utilizing this information, we tentatively correlate the prominent More Mesa terrace (of unknown age) with the Isla Vista terrace (dated at 47ka). This allows the estimation of ages of several other higher terraces at More Mesa and Hope Ranch adjacent to the Mission Ridge Fault System and associated folds. We then use the assigned age to calculate the rate of uplift, presumably related to earthquake activity and folding. Use of oxygen isotopes offers an exciting potential tool to assign ages (via correlation) to terraces of unknown age with the objective of calculating rates of deformation. We believe we can delineate isotope stage 3 from stage 5, but further studies will be needed to distinguish substages of stage 3 or 5 (i.e. 5a from 5c or 5e).

Damage and Restoration of Geodetic Infrastructure Affected by the 1994 Northridge, California, Earthquake

Kathleen M. Hodgkinson and **Ross S. Stein** , U.S. Geological Survey, Menlo Park
Kenneth W. Hudnut, U.S. Geological Survey, Pasadena
Jay Satalich, California Department of Transportation
John H. Richards, National Geodetic Survey
Anne Lilje, California Institute of Technology

Because the Northridge earthquake deformed the ground surface, the network of geodetic monuments used by engineers and surveyors for construction and monitoring of the urban infrastructure was distorted and rendered inaccurate. We resurveyed the height of 979 leveling bench marks (BMs) and the positions and heights of 66 GPS monuments; emplaced 252 new BMs where the previous BMs were lost or unrecoverable, and added 128 new GPS monuments along critical highways for rapid damage assessment after future earthquakes. Because half of the BMs are located on engineered structures, their displacement not only records the permanent change in height caused by the earthquake, but also any disturbance of the structures caused by shaking. After correcting for non-tectonic subsidence and surveying error, we developed a variable-slip model of the deformation that is consistent with the movement of the geodetic monuments. The 40 BMs with residuals more than 3 cm are considered to be anomalous. Those located in engineered structures include railroad and highway bridge abutments and spans, tower and building foundations, catch basins, retaining walls, and culverts; the remainder are typically in engineered fill. Structures associated with anomalous BMs may be in a weakened state, making them vulnerable to shaking during future earthquakes. Because few structures have been assessed for earthquake effects except by visual inspection, subtle or hidden damage suggested by the settlement or uplift of the structures merits re-inspection. To ensure faster and more accurate post-earthquake damage assessments in the future, we further suggest that more geodetic monuments be placed on critical transportation arteries, structures, and lifelines. (This study published as U.S.G.S. Open-File Rep. 96-517 [1996], including text, map, and CD-ROM. It is also available on <http://www-socal.wr.usgs.gov/fema/>

Tectonics of the Montebello Anticline, the East Montebello Fault, and the 1987 Whittier Narrows Earthquake

Gary J. Huftile
Oregon State University

Uplift following the 1987 Whittier Narrows earthquake centered around the Montebello anticline. While the earthquake and its aftershocks suggest a north-dipping fault, the Montebello anticline is north-vergent, related to a south-dipping fault.

The East Montebello (EMF, Alhambra Wash) fault dips steeply to the northeast and truncates the eastern end of the Montebello anticline. It constitutes the northern extension of the Whittier fault. Long term rates are based on the offset of conglomerate and sandstone isolith contours of the Lower Repetto and Middle Repetto members of the Fernando Formation. These conglomerates were deposited southwesterly across the fault in bathyal water depths as channel facies in a submarine fan.

The isolith maps show greater right-lateral displacement along the EMF for the Lower Repetto than for the Upper Repetto. Average displacement rates for both horizons is 0.4 mm/y. E. Gath, in his trenching of the Alhambra Wash fault to the north, found a displacement rate of 0.1 mm/y. The Montebello anticline is hypothesized to take up the remaining 0.3 mm/y of displacement.

Seismic Spectra Recorded at the Surface and 3 km Depth at Mojave Borehole

Anshu Jin and **Kei Aki**
University of Southern California

It has been a long standing debate whether the observed f_{max} and departure of seismic scaling law from self-similarity are source, site or path effect. Although, the spectral ratio method may eliminate the path and site effect by using doublets, the high frequency falloff still could be attributed to the unrecoverable absorption by the surface layer under the receiver. By analyzing Mojave borehole data set, we found that: (1) The signal/noise ratio for both downhole and surface records is frequency dependent. The cutoff frequency (the frequency corresponding to S/N<= 2) is also magnitude dependent. For example, the cutoff frequency is around 20 Hz and 50 Hz for surface and downhole records for M~2 events at this site. Therefore, the resultant measurements with corner frequencies or f_{max} higher than the corresponding cutoff frequencies may not be reliable. (2) Since the instruments at the surface and downhole were very different (1 Hz and 10 Hz) with very narrow frequency overlapping, direct comparison between these two data sets is difficult and may not be reliable. We found 3-pairs of doublets with M2 to 3.5 recorded at both surface and downhole(3 km depth). The resultant corner frequencies for these events agree with each other by using surface and deep records.

Evidence for Power-Law Behavior in Geodetic Time Series: Should You Care, and if so, Why?

Hadley Johnson
University of California, San Diego

We present evidence for power-law behavior in geodetic time series using data from continuous GPS data from the SCIGN network in southern California and nearly-continuous two-color EDM measurements from Parkfield. The power spectra of these data demonstrate power-law behavior with spectral indices between about -1.1 and -3.3. In addition, we use these data to estimate the amounts of each noise source when we restrict the spectral index to values of -1 (flicker noise) or -2 (random walk noise) at the low frequency end of the spectrum, and white noise at the high frequency end. Typically we find random walk components of between 1 and 3 mm/sqrt(yr) with similar values if we model the data using flicker noise.

The implications of this type of power-law noise are profound if the data are to be used to estimate low-frequency characteristics of a time series such as its slope (deformation rate), and can easily increase the velocity uncertainties by an order of magnitude as compared to values derived from a white noise only model given a 5-year long time series.

Geomorphologic and Structural Analysis of the Stage 5e Marine Terrace, Malibu Coast, California Suggests That the Santa Monica Mountains Blind Thrust Fault is no Longer a Major Seismic Hazard

M. L. Johnson*, J.F. Dolan, and A. Meigs
University of Southern California
*** SCEC Summer Intern**

The Santa Monica Mountains anticlinorium is believed to overlie a major blind thrust fault (Elysian Park thrust fault of Davis et al., 1989; Santa Monica Mountains thrust fault of Dolan et al., 1995) that has been suggested to pose a major seismic hazard to metropolitan Los Angeles. Disputes about the geometry and slip rate on the blind thrust fault however, have complicated the seismic hazard assessments of the region. Davis and others (1989; Davis and Namson, 1994), proposed a long-term slip rate for the fault of 3.9-5.9 mm/yr averaged over the past 2-3 Myr.

In an effort to determine if the long-term slip rate proposed by Davis and Namson is correct, we mapped the oxygen isotope substage 5e marine terrace along the Malibu coast, from Pacific Palisades to Point Dume. At this location the marine terrace extends along the southern edge (forelimb) of the anticlinorium. Our data indicate that uplift of the inner edge of the stage 5e marine terrace is due mostly to motion along the surficial faults of the Santa Monica and Malibu Coast fault systems. Although the terrace is locally deformed by short-wavelength folds and uplift on surficial and near-surface fault, regionally it dips gently seaward (~1°), suggesting that it has not been significantly tilted by anticlinal growth. This inference is supported by the flat-lying nature of post-Pliocene strata along the southern edge of the anticlinorium.

A profile of the stage 5e terrace inner edge reveals a terrace uplift rate of 0.2-0.4 mm/yr, after uplift on surficial faults has been removed. This calculated rate indicates that during the past ~125 Ka uplift has been much slower than expected using the long-term (past ~2-3 Ma) average slip rates and blind thrust fault model proposed by Davis and Namson. These data suggest that the Santa Monica Mountains blind thrust fault is either inactive, or is slipping at a very low rate (<1 mm/yr). Thus, the Santa Monica Mountains blind thrust fault appears to pose a much less severe seismic hazard to the metropolitan region than previously thought.

STRESS IN SOUTHERN CALIFORNIA, 1850-1996

Yan Y. Kagan and **David D. Jackson**
University of California, Los Angeles

We compute the incremental stress tensor in the upper crust of southern California and compare observed seismicity with the estimated stress increment at the time of each earthquake. Several recent developments make it possible to do this much more realistically than before: (1) a wealth of new geodetic and geologic data, (2) a model for calculating elastic stress accumulation in a faulted medium, and (3) a catalog of moment tensors for all earthquakes with magnitude larger than 6 since 1850. Several other catalogs of fault-plane solutions are used in this study: Harris et al. (1995) list of southern California earthquakes 1968-1993, Jones (1993) catalog of earthquakes 1986-1993, and the list of 1990-1995 moment-tensor inversions of Terrascope records (Thio and Kanamori, 1995; 1996). We model crustal deformation using updated geodetic, especially GPS, data and geologically determined fault slip rates. Between earthquakes, a fault moves freely below a locking depth with a rate determined by the relative elastic block motion. We compute normal and shear stress on nodal planes for each earthquake in the catalog. We compare the locations of earthquakes with the resolved shear and resolved compression stress before the earthquakes. We consider the stress increments from previous earthquakes, and the aseismic tectonic stress, both separately and in combination. The locations and mechanisms of earthquakes are best correlated with the aseismic shear stress, which grows at a constant rate in our model. Inclusion of the cumulative coseismic effects from past earthquakes does not significantly improve the correlation. The variations in normal stress, either from the seismic or aseismic sources, do not correlate well with earthquake locations and mechanisms. In general, correlations between stress and earthquakes often change significantly if we modify even slightly initial parameters of our computations. We consider the statistical distribution of deformation to see the extent to which the accumulated stress is released by the largest earthquakes in California.

Bending Modes of Slip in Earthquake Ruptures

Leon Knopoff
University of California, Los Angeles

Measurements of E_S/M_0 show that San Andreas/San Jacinto fault earthquakes have low average stress drops (Kanamori, et al., 1993), while the heat flow measurements imply low dynamic friction during faulting (Henyey and Wasserburg, 1971; Lachenbruch and Sass, 1980). Models of breakout from asperities into faults of low stress drop in both 1-D or 2-D antiplane cases show that long fractures with large slip cannot be developed on faults with low stress drop, because of high loss of crack energy in seismic wave radiation.

The situation is different in the plane-strain case of the development of slip on a fluidized crack. As a prototype calculation, we solve exactly by the Cagniard-deHoop method the problem of the plane strain release of shear stress at a point asperity (double-couple source) at a plane fluid interface between two half-spaces. Because the normal component of stress and slip are continuous across the fault interface, crack opening or Schallamach modes are forbidden by the antisymmetry of the problem. Slip along the interface is dominated by antisymmetric Stoneley modes that travel with the Rayleigh wave velocity. The interface thus acts as a waveguide that concentrates slip near the fault and prevent seismic wave energy from being radiated to infinity. During dynamic rupture, the fault bends in the normal direction as the Hilbert transform of the slip along the fault, as expected for Stoneley/Rayleigh motions.

Because of the waveguide properties of the crack interface, large moments can be generated over long fractures with low friction without radiating large amounts of seismic energy. Because of the trapped mode structure along faults (Li, et al.), strong earthquake source motions that are dominated by surface wave modes of slip are expected to be strongly oscillatory. We cannot contribute to the discussion whether the low friction pre-existed the earthquake or was initiated by the passage of the P- wave component of the slip.

Integration of Passive with Active Phase Data Analysis: the Los Angeles Region Seismic Experiment (LARSE)

Monica D. Kohler and **Paul M. Davis**
University of California, Los Angeles

During the Los Angeles Region Seismic Experiment passive phase (LARSE93), 88 seismometers were deployed in a 175-km-long, linear array across the Los Angeles basin, San Gabriel Mountains, and Mojave Desert northeast of Los Angeles. Each site recorded 140 teleseismic events and 400 local events. The densest part of the array was located in the San Gabriel Mountains with one km spacing; the less dense part, in the Mojave Desert, has two km spacing. This experiment was followed by LARSE94 which involved land refraction and deep-crustal seismic reflection profiles from offshore and onshore explosion sources. The joint data sets have been used to distinguish upper crustal features from adjacent lower crustal and upper mantle structures. P-wave travel times were determined from 20 intermediate-magnitude earthquakes with epicenters in the Aleutian Island, Kamchatka, Kuril Island, mid-Atlantic Ridge, Solomon Island, Japan, Chile, and Fiji Island regions. Upper crustal velocity signatures were removed by incorporating LARSE 94 upper crustal model velocities. Within each back-azimuth range, the resulting travel-time residuals increase from negative values (-0.5 s average) recorded in the northernmost San Gabriel Valley to positive values (0.2 s average) in the central and northern San Gabriel Mountains. The residual patterns display small variations for different back azimuths and incidence angles, but show almost no lateral spatial shift of maximum or minimum residual along the array, indicating that the source of the residual is shallow. The patterns of residuals require a sharp gradient in shallow velocities between the Los Angeles basin and the San Gabriel Mountains over a horizontal distance of less than 50 km.

We have analyzed the residuals with two approaches: 1) raypath back-projection to obtain Moho depth variations, and 2) simultaneous inversion to obtain lateral velocity variations in a slice beneath the array. Back-projection produces a Moho depth decrease of 10-12 km between the San Gabriel Mountains and Los Angeles basin when we assume an average crustal velocity of 6.3 km/s and upper mantle velocity of 8.0 km/s. The decrease in crustal thickness beneath the Los Angeles basin is supported by evidence for crustal extension in southern California rocks. Simultaneous inversion of the LARSE93 residuals, combined with Southern California Seismic Network teleseismic residuals and incorporating the depth-varying Moho, produces a ~50-km wide high-velocity anomaly below the San Gabriel Mountains. This anomaly extends from the base of the crust and dips steeply northeast, juxtaposing more normal upper mantle on either side.

2D Elastodynamic Simulations of Earthquake Sequences in a Faulted Crustal Plate That is Loaded by Coupling to a Steadily Moving Substrate

Nadia Lapusta, James R. Rice, and **Gutuan Zheng**
Harvard University

A 2D elastodynamic model is adopted of a faulted crustal plate, coupled to a steadily moving substrate, and we study its predictions of earthquake sequences. The model is based on the Lehner-Li-Rice generalization of Elsasser coupling to a substrate, as extended to dynamics by Johnson (*GJI*, 1992) but simplified in a scalar wave sense like in Langer et al. (*Proc. NAS*, 1996) and Myers et al. (*Phy. Rev. Lettr.*, in press). The nondimensional description for along-fault displacement u(x,y,t), averaged over seismogenic depth, is

$$\delta^2 u/\delta x^2 + \delta^2 u/\delta y^2 + (V_{pl}\, t / 2 - u) = \delta^2 u / \delta t^2 \quad \text{in } y > 0,$$

where x and y are in the plane of the plate, the fault is on y = 0, and V_{pl} is the substrate loading rate. The depth-averaged stress, proportional to $\delta u(x,0,y)/\delta y$, and slip 2 u $(x,0^+,t)$ are related by rate and state dependent friction laws. We have developed a spectral numerical procedure for this class of problems, similar to that of Perrin et al. (*J. Mech. Phys. Solids*, 1995) as used in 2D dynamic simulations of earthquake sequences in a depth-variable fault model by Rice and Ben-Zion (*Proc. NAS*, 1996), and incorporating techniques on calculation of time convolutions developed by Zheng et al. (*EOS*, 1995) for loading processes of long duration.

The question under investigation is whether it is possible to obtain slip history complexity in this model when properties are uniform along strike. Rice and Ben-Zion (*Proc.

NAS, 1996) and Cochard and Madariaga (*JGR*, in press) have found complexity in uniform fault models, rigorously analyzed within a continuum limit, only for special choice of constitutive parameters. We seek to learn if the further ingredient in the present model of coupling to a substrate, and also use of constitutive descriptions which combine a pair of weakening mechanisms with significantly different nucleation sizes and strength drops, will alter those conclusions.

Seismicity On Multiple Interacting Heterogeneous Faults

Matthew W. Lee, Leon Knopoff and **Didier Sornette**
University of California, Los Angeles

We consider multiple interacting faults in proximity, in an elastic model driven under anti-plane strain conditions. Fractures occur as quasistatic cracks with inhomogeneous stresses redistributed elastically by long range forces. The fracture strength of an elastic element begins to decay significantly when the prestress crosses a subcritical threshold. For throughgoing parallel faults with a heterogeneous distribution of breaking strengths we find the system settles into a state of many ruptures along a single fault that minimizes energy, while the other faults remain silent. The system persists in this behavior for many thousands of events, comparable to very long geologic times. As the heterogeneity is increased we find that a formerly quiescent fault is excited into activity, and the formerly active fault becomes quiet. After some time, activity again switches to another fault; in the case of only two interacting faults, activity flips between the two. The flipping of activity only occurs for fault heterogeneity above a certain threshold. Thus knowledge of fault heterogeneity might aid in the prediction of seismicity on multiple interacting faults, and in particular whether or not a long dormant fault should be expected to reactivate.

Evaluation of Empirical Regressions for Ground Motion Characteristics

Yajie Lee, Yuehua Zeng, John G. Anderson, Shear-Der Ni, Feng Su
University of Nevada, Reno

For a probabilistic seismic hazard analysis, an essential part of the input is an attenuation equation. In brief, this is an equation in which the magnitude and distance from the fault are used as input, and the amplitude of a ground motion parameter is predicted as output. These equations are generally also specialized for different categories of site conditions.

Numerous regressions exist. This study selects six of the most recent ones that were judged likely to be appropriate for southern California region, and attempts to determine which is most successful in prediction of ground motion parameters in this region. The regressions we test are originally developed for different, larger geographical areas. Another specialized feature of the SCEC application is the way we categorize site conditions. Our application requires that they be categorized somewhat differently from the way they are categorized when the regressions were developed. Thus, even though each regression is optimized for the data that was used in its development, it might not be optimized for the specific application in this study.

Considering these specialized requirements, our purpose is to determine which regressions are satisfactory for our applications.

Observations, Simulations and Implications of Fault-Zone Guided Waves at the San Andreas Fault, the San Jacinto Fault and the Landers Fault, California

Yong Gang Li and **Keiiti Aki**
University of Southern California

Co-authored by William Ellsworth of the USGS, Clifford Thurber of UW at Madison, Peter Malin of Duke University, and Frank Vernon of UC at San Diego, we reported the results from observations and simulations of fault-zone guided waves excited by explosions and earthquakes at the San Andreas fault, the San Jacinto Fault and the Landers fault, California in our two recent papers submitted to the BSSA and JGR.

Fault-zone guided waves were successfully excited by explosions in the San Andreas fault zone both at Parkfield and Cienega Valley, central California. The guided waves were observed on linear seismic arrays deployed across the fault trace. The amplitude spectra of guided waves show a maximum peak at 2 Hz at Parkfield and 3 Hz at Cienega Valley. The guided wave amplitude decays sharply with observation distance from the fault trace. The explosion-excited fault-zone guided waves are similar to those generated by earthquakes, but have lower frequencies and travel more slowly, suggesting that the fault-zone waveguide has lower seismic velocities and/or broadens as it approaches the surface. We have modeled the waveforms as S waves trapped in a low-velocity waveguide sandwiched between high-velocity wall rocks, resulting in Love type fault zone guided waves. The Parkfield data are adequately fit by a shallow waveguide 170 m wide with a S-velocity 0.85 km/s and an apparent Q ~30-40. At Cienega Valley, the fault-zone waveguide appears to be about 120 m wide with a S-velocity 0.7 km/s, and a Q ~30.

The fault-zone trapped wave data collected by three linear seismic arrays deployed at the San Jacinto Fault Zone near Anza, California, also provide detailed information on the fault structure at depth. We observed fault-zone guided modes at the Casa Loma fault (CLF) and the San Jacinto fault (SJF), but not at the Hot Springs fault (HSF). The amplitude spectra of the guided waves showed a peak at 4 Hz on the CLF, and 6 Hz on the SJF, which decreased sharply with the distance from the fault trace. Finite-difference simulations of these guided waves result in: a 120 m-wide waveguide exists on the CLF, and it becomes 50-60 m on the SJF in the Anza slip gap; the S-velocity within the waveguide is reduced by ~30 percent on the CLF, and by ~20 percent on the SJF. Location distribution for the events with guided modes infers that this fault-plane waveguide, dipping northeastward at 75-80^{0}, extends from the surface to the depth of at least 18 km. We tentatively interpret that this low-velocity waveguide along the CLF was a result of the rupture of the 1899 M7.0 earthquake occurring near the towns of Hemet and San Jacinto.

In collaboration with a field research team from the SCEC, USGS and IRIS (D. Adams, D. Bowman, J. Wedberg, M. Forrest, A. Martin, G. Ely, A. Wei and T. Burdette), we carried out an experiment to record explosion-excited guided waves trapped in the fault zone of the 1992 Landers earthquake. We deployed two 4 km-long and one 10 km-long linear arrays consisting of 68 PASSCAL portable instruments across and along the Landers fault. Three explosions using 500-1200 lb. of chemical emulsions were detonated within the fault zone at distances of 2 km, 5 km and 15 km from the 1992 mainshock epicenter. The data collected from this experiment are compared with those recorded in our previous experiments at Landers in 1992 and 1994 to search for any changes in arrival times, amplitudes, frequency contents of fault-zone guided modes. The results may provide evidence for the post-seismic healing process of an earthquake fault zone.

COMPARISON OF SEISMIC APPROACHES FOR STRONG GROUND MOTION PREDICTION USING WEAK MOTION DATA

H. Liu, S. Gao, P. M. Davis, and L. Knopoff
University of California, Los Angeles

Three component velocity seismograms from a Northridge earthquake aftershock recorded by 62 stations in the San Fernando Valley, Santa Monica Mountains, and Santa Monica, California are used to quantify the relations between amplification factors derived from different methods, including P- and S-wave peak amplitudes, P- and S-wave spectral ratios, and coda wave spectral ratios.

Some main conclusions include: 1). Site amplification factors derived from S-wave peak amplitudes are correlated with the damage pattern; 2). Coda wave amplification factors obtained from the vertical and the horizontal components are correlated with a mean correlation coefficient of 0.73 +- 0.23, justifying the use of S-coda waves recorded on vertical seismograms as an estimate of coda amplification factors; 3). In areas where the damage was mainly caused by geological structure effects such as mid-Santa Monica, coda wave amplification factors are not correlated with the damage pattern caused by the main shock; 4). The good correlation between S-wave peak amplitudes and the damage pattern may imply that damage to 1-2 story low buildings is more likely to be caused by impulsive strong pulses in a very short time (1-2 seconds) than by the continuous oscillation by lower amplitude waves operating over a few seconds or tens of seconds; 5). Future microzonation for a given area should take into account more than one method to estimate hazard including assessment of the effect of local geological structure and source location.

3-D Finite-Difference Simulation of a Dynamic Rupture

R. Madariaga
Inst. de Physique DU Globe, Paris
K. B. Olsen and **R.J. Archuleta**
University of California, Santa Barbara

We have used a 4th-order staggered-grid finite-difference method to analyze dynamic faulting in a three-dimensional medium. In order to simplify the computations we use the scalar rather than the elastic wave equation. However, all the properties of dynamic faulting are retained, including friction, rupture initiation, and spontaneous rupture growth and healing. The numerical method is used to study spontaneous rupture from a finite asperity on a rectangular fault. We arbitrarily choose the radius of the asperity to be 5 grid elements, and the initial stress inside and outside the asperity to be respectively 1.2 and 0.7 times the peak stress. The excess stress on the asperity is required to generate an initial "kick" to the rupture. We use two friction laws: (1) slip weakening, that satisfactorily regularizes the rupture front, and (2) slip weakening plus slip-rate dependent friction. The rupture is forced to stop when it reaches the pre-determined boundaries of the faults. The rupture simulation clearly shows the initiation of the rupture followed by its growth at an accelerating rate. The rupture speed is close to that of the acoustic waves when the rupture is terminated. After the abrupt termination of rupture stopping phases are generated from the edges of the fault. Healing (arrest of slip) occurs very soon hereafter. The use of slip rate-weakening friction law produces very fast, almost instantaneous healing phases with finite slip duration. Such healing phases were suggested by Heaton (1989).

An interactive Software for Seismic Hazard Analysis in Southern California

Mehrdad Mahdyiar
VortexRock Consultants, Inc.

Probabilistic seismic hazard analysis (PSHA) is a multidisciplinary problem that requires the integration of the geologic, geodetic, and seismic data in conjunction with the information on the local site conditions. There are uncertainties in most of these parameters. Therefore, it is necessary to evaluate the effects of various types of uncertainties on the results of the PSHA. The objective of this project is to develop a user friendly software for the PSHA in southern California that enables both geologists and seismologists to perform parametric studies.

An interactive software for the PSHA in southern California based on the SCEC and Dolan et al. databases is developed. Three sites at Palm Spring, Palos Verdes, and Ventura area are selected for the parametric studies. At these sites the probabilistic seismic hazard curves based on the preferred source parameters of the Dolan et al. and SCEC models are calculated. For the purpose of the parametric studies the user can change the basic input parameters for each seismic source to construct a new seismicity model and observe the related effects at the three sites. The selected variables are the slip rates, strain rates, rates of seismicity from the catalog data, upper bound magnitudes, magnitudes of the characteristic earthquakes, and b-values. The user can define the method of integration of the geologic, geodetic, and seismic data. The user also has control over the construction of the magnitude distribution of earthquakes within each seismic source, i.e. any combination of the Gutenberg-Richter and characteristic earthquakes. The results of the PSHA are presented in the form of the hazard curves and the deaggregation of the magnitude-distance contribution to hazard for different periods.

Probabilistic Seismic Hazard Analysis in Southern California

Mehrdad Mahdyiar
VortexRock Consultants, Inc.

One of the main achievement of the Phase II Report was the integration of the geodetic, geologic, and seismic data for the faults and seismic sources in southern California for the purpose of the probabilistic seismic hazard analysis (PSHA). However, the preferred Phase II model is one interpretation of the seismicity in southern California. The recent philosophy on the PSHA is to obtain PSH values based on different databases and then integrate the results. It is the objective of this study to perform the PSHA in southern California using different source models and compare the results.

Using the catalog earthquake data Kagan and Jackson have calculated the probable rate of occurrence, strike, dip, and rake of earthquakes at a number of grid points in southern California. A PSHA program that uses this information has been developed. The interesting aspect of this database is that it provides the most probable faulting mechanisms and dipping angles for the rupture areas of the future earthquakes at different locations. The long term objective of this study is to integrate all the available databases for the earthquake source models for southern California and the related PSHA programs into a software package (see Mahdyiar's other abstract on the subject) in order to enable geologists and seismologists to perform parametric studies on the PSHA. The preliminary results that are presented here show the PSH values at selected sites based on the Kagan-Jackson, catalog earthquake data, SCEC Phase II Report, and Dolan et al. models.

Integrated Los Angeles Area Velocity Model

Harold Magistrale
San Diego State University

This preliminary 3D model demonstrates a method of integrating the geology based model of the Los Angeles basin sediments and earthquake travel times. The geology based sediment model, embedded in a 1D basement rock model, is used as a starting model in an inversion of travel times of 3700 selected local earthquakes to obtain P wave velocities. The model is parameterized as 6760 blocks that are 5 by 5 km in area and 2 to 5 km thick. The quality (expected standard deviation of the block slowness) of each model block is judged and block velocity changes during the inversion are individually damped accordingly. Model blocks representing the basin sediments are presumed to have well controlled velocities at shallow depths, with uncertainties increasing with depth. Blocks representing the basement rocks are assigned large uncertainties at all depths. The final model fits the travel times very well, providing realistic basement rock velocities. In the sediments, differences between the starting and final models show areas of poor control in the geologic model, or where alternate geologic inputs could be used.

Preliminary Paleoseismic Results from the San Andreas Fault at City Creek, near San Bernardino, California

Sally McGill
California State University, San Bernardino

I report here the preliminary results from a trench excavated across the San Andreas fault within the flood control channel of City Creek, in Highland, California. The trench crossed the South Branch of the San Andreas fault zone, which is the dominant strand of the fault. The uppermost naturally deposited unit in the southern half of the trench (unit A) was unaffected by any of the fault strands visible in the trench. Pending radiocarbon dates from this unit may place an upper bound on the date of the most recent large earthquake at this site. Unfortunately, this unfaulted unit was eroded in the northern half of the trench by a younger channel which was then filled with bouldery gravel. No faults were visible within the bouldery channel fill, but it is possible that this young channel has destroyed evidence for faulting events that post-date unit A.

Only one well-documented faulting event was visible within the trench. Its stratigraphic position is about 1/2 meter above a dark (organic-rich?) clayey sand layer (unit B), which has a calibrated radiocarbon age of A.D. 975-1235. Additional radiocarbon dates are pending that will bracket the age of this faulting event. It would be very surprising if there has been only one large earthquake on the San Bernardino segment of the San Andreas fault since A.D. 975-1235. Other scientists have found evidence for several faulting events at Wrightwood and Pitman Canyon within this same time period. Either the trench at City Creek does not provide a complete paleoseismic record for the past 1000 years, or many of the earthquakes recorded at Pitman Canyon did not rupture as far southeast as City Creek.

Updated Assessment of Worldwide Performance of the M8 Intermediate - Term Earthquake Prediction Algorithm, M > 7.5, 1985 - 1996

Jean-Bernard H. Minster and Nadya P. Williams
University of California, San Diego

We have updated the Receiver Operating Characteristic (ROC) curve for the M8 algorithm, based on worldwide seismicity ($M > 4.0$) between 1963 and 1996. The present test applies to 35 events with $M > 7.5$. The ROC is defined as the proportion of successful predictions in the chosen region vs. the volume of space-time during which an alarm is declared. "Space" is the complete set of points on Earth where the algorithm can actually be executed. "Time" is the period 1985 - 1996. Our decision rule is that the likelihood that a TIP exceeds a given threshold is L_0. Our Null Hypothesis is that the algorithm performs no better than a random sampling of space-time with a uniform probability density. This yields a hypergeometric distribution for the 95% confidence band.

We recognize three regimes: (1) For L_0=0.2, M8 performs better than random at nearly 95% confidence, (31% success rate, over 25% of space-time, 11 events). (2) For L_0 < 0.2, (31-80% success rate, over 25-75% of space-time, 17 events) the null hypothesis cannot be rejected, and M8 performs no better than random. (3) Finally, for the remaining 7 events, no successful prediction is possible at any positive likelihood threshold.

Structural Analysis and Geomorphology of Folds Produced above Blind Thrusts in the Greater Los Angeles Metropolitan Area

Karl Mueller
University of Colorado

Blind thrusts do not displace Earth's surface. Therefore, analysis of active fault-related folds which develop in response to slip on these potentially hazardous, and otherwise inaccessible thrusts is used to define whether they are active and pose a risk of future damaging earthquakes. As part of collaborative efforts with a number of other SCEC Group C researchers, I present the following progress report on structural, and geotechnical studies aimed at determining the activity of blind thrusts in the greater Los Angeles area.

Compton-Los Alamitos Trend Trenching and Cone Penetrometer Test (CPT) studies focused on documenting bending of very young sediments along the predicted location of the active axial surface mapped by Shaw and Suppe (1996) at the base of the Compton Ramp have not found evidence for movement since the deposition of the Gaspur Aquifer (~20ka). This leads to several possible branches on the "Compton Logic Tree" for probabilistic modeling of future earthquakes along the thrust. These are outlined below from greater to lesser likelihood:

1) The Compton-Los Alamitos blind thrust is now inactive, after having slipped at a rate of 1.3mm/yr for the last 2.5 Ma (Shaw and Suppe, 1995).
2) Fault-bend folding does not propagate completely to the surface until many (>10?) events occur (i.e. it is not possible to document single folding events on low angle ramps).
3) The assumption that earthquakes occur regularly along the thrust is invalid, as are current regressions that relate the magnitude of surface displacement with fault area (e.g. Wells and Coppersmith, 1993). This improbable branch on the logic tree implies very large, infrequent earthquakes on the Compton blind thrust for the late Quaternary.

San Joaquin Hills-Irvine Thrust The geometry of marine terraces deformed around the northern San Joaquin Hills indicates tectonic uplift over an area extending from the city of Irvine south to Laguna Beach. Structural models completed in collaboration with data compilation and mapping efforts of deformed terraces by Lisa Grant, Eldon Gath and Rosalind Munro indicate:

1) The San Joaquin Hills is probably produced by fault-bend folding above a gently NE-dipping thrust ramp.
2) Slip decreases on the thrust to the north in the southern Los Angeles Basin, with a probable segment boundary near the Santa Ana River.
3) The thrust is the southerly continuation of the Compton-Los Alamitos trend, based on the location and geometry of the San Joaquin Hills and similar rates of uplift (i.e. 1.4mm/yr) using existing age constraints for the marine terraces.

Although there is abundant evidence for Quaternary uplift of the San Joaquin Hills that is consistent with structural models developed for the buried Los Alamitos trend immediately to the north, it has not yet been demonstrated whether the fold is presently active (i.e. within the last 10-20 ka). Grant and Gath are therefore examining exposures around the Bolsa Chica Lagoon for evidence of uplift of very young terraces of possible Holocene age.

East Los Angeles-Repetto Hills

As part of a collaborative geotechnical and mapping project in East Los Angeles headed by Kerry Sieh and Mike Oskin I am completing structure contour maps and balanced cross sections across two active folds, the "Freeway Anticline" which extends along I-60 and the "Coyote Escarpment", a south-facing fold limb lying south of the I-10 corridor. Sieh and Oskin's mapping and geotechnical studies suggest that progressive limb rotation of young strata (Fernando Fm) is the dominant mechanism by with the Coyote Escarpment grows. In addition, the Freeway anticline gently warps Holocene strata in the LA River floodplain.

These surface data, coupled with initial subsurface mapping using petroleum well logs from the Union Station and Boyle Heights oilfields, and other areas indicates these structures were not produced by classical models of either fault propagation folding, or fault-bend folding. My current efforts besides completing several closely-spaced cross sections include modeling of growth architecture formed above progressively rotating folds. An important outcome of the compilation of petroleum well data is the obvious continuation of these structures directly beneath downtown Los Angeles (i.e. the Los Angeles City oilfield) which has obvious implications for strong ground motion studies aimed at tall steel frame buildings.

A Study of Site Effects from a Dense Accelerograph Network

Gretchen Mullendore
SCEC Summer Intern
University of California, Santa Barbara

The Van Norman Complex (VNC), which consists of the Los Angeles Dam, Jensen Filtration plant, and related facilities, is located 35 km northwest of the Los Angeles basin. During the Northridge earthquake in 1994, the array or strong-motion accelerometers located at the dam recorded peak accelerations from 0.30g to 0.86g over an area of only 1200 meters (Bardet and Davis, 1996). This large variation in peak acceleration was unpredicted behavior, and provided an impetus for further investigation into this area.

The objective of this project is to study the variability of ground motion at the VNC through spectral analysis. Soil records are compared with a rock record from Pacoima Dam for the 1994 Northridge earthquake. Pacoima Dam was chosen because it is the closest (≈7 km from VNC), crystalline rock site.

The soil and rock sites were compared both in the time domain (accelerograms) and frequency domain (Fourier spectra). Spectrograms, which attempt to isolate the signal in both frequency and time were also used. A spectrogram is a power spectrum generated from Fourier spectra of sequential, overlapping time windows.

The main difference observed thus far that separates the records of the soil from those of rock is that the Fourier spectra show that the soil stabilizes the low frequencies while strongly attenuating the high frequencies. The rock spectrum is more consistent with the expected shape (Brune, 1970).

The spectrograms reinforce these findings and provide additional insight into the behavior of the sites over time. The spectrograms show, for instance, that the soil site exhibits a lack of amplitude in the high frequencies throughout the entire record, even at the first arrivals.

With the study of more records from the VNC, it is expected that these characteristics will become clearer, and reasons for this behavior will become better defined.

Expected Signature of Nonlinearity on Regression for Strong Ground Motion Parameters

Shean-der Ni, John G. Anderson and **Yuehua Zeng**
University of Nevada, Reno

Nonlinear behavior of soil plays an important role in changing both the amplitude and spectral peak of the strong ground motion on soil sites. This study treats several hundred synthetic seismograms, generated to represent rock ground motions from a magnitude 6.4 scenario earthquake, as input at the base of a model soil profile with nonlinear properties. Four shear wave velocity models (developed to represent class BC and C sites with saturated and unsaturated conditions) are tested. The computed ratios of peak ground acceleration (PGA) between the surface of the soil profile and the bedrock are a decreasing function of input PGA values. The transition from amplification to deamplification occurs at about 0.2-0.4g. These transition PGA values are higher for unsaturated cases than saturated cases, which reflects the stiffer property of unsaturated soil. This study also examined spectral acceleration (SA) ratios, defined as the ratios of SA between the surface of the soil profile and the input. These SA ratios vary with the natural periods considered. At short periods less than 0.3-0.5 s, the SA ratios behave similar to PGA ratios: they show amplification for lower input SA and deamplification for higher input SA level. At longer periods, the influence of input SA level on SA ratio decreases, and very few examples of deamplification are observed.

We define the mean trends of these calculations as "regression modification curves." The use of these curves is as follows: a regression prediction for ground motions on rock is multiplied by the "rmc" for that ground motion to obtain the expected regression predictions on soil. This procedure is applied to six sets of empirical attenuation curves. Some of the empirical curves are more consistent with the model than others.

In the best case, the comparisons indicate that the empirical soil site PGA and SA attenuation curves are very close to the predicted curves at all distances. The empirical curves are mostly bracketed the predicted curves for the saturated and unsaturated cases, except for the SA attenuation curve at 0.3 s. For both PGA and SA, the differences between the empirical and predicted curves are within one standard deviation for the empirical curves.

Several other empirical regressions show a similar trend, and thus are more consistent with a nonlinear model of soil amplification than with a linear model. Thus the nonlinear soil model used in this paper is not rejected by attenuation relations. On the contrary, it is quite encouraging that this physical model for soil behavior is actually successful in predicting average ratios in this highly scattered data set.

A Model for the Sticking and Slipping of Blocks with Rough Surfaces: Implications for the Earthquake Rupture Process

Xiao-xi Ni and **Leon Knopoff**
University of California, Los Angeles

We construct a one-dimensional model of the elastic interaction of two blocks, each having an irregular surface. Under a load stress, the blocks deform according to static elasticity at the points of contact. The elastic deformation of the contacts is modeled by the deformation of overlapping elastic vanes that protrude from opposing blocks. The frictional resistance is gauged by the overlap between opposing vanes. When vanes break they transfer stresses to their neighbors dynamically by elastic stress wave propagation through a series of longitudinal coupling springs. Dynamic friction is a consequence of the partial loss of momentum by the mass of the vanes upon collision with opposing vanes. Unlike the Burridge-

Knopoff model, the static and the dynamic friction are not pre-defined, but are determined by the overlap of the vanes on the two opposite blocks.

The vane model is applied to simulate the evolution of seismicity on an earthquake fault having an irregular geometry and to examine the rupture process of earthquakes. In the case of the breakout of a strong asperity into an extended region with negligible friction (zero overlap), we observe an initial nucleation phase that is very much smaller than that of the main, breakout phase. There are features that simulate the decay of strength in the asperity as the critical state of breakout approaches. Thus the study of the small ruptures in the nucleation phase may give insights into the precursors of large earthquakes.

Seismicity Studies of the Santa Barbara-Ventura Area

Craig Nicholson
University of California, Santa Barbara

A geophysical study of velocity and seismicity was conducted across the Santa Barbara Channel, eastward into the Ventura Basin, and northward across the western Transverse Ranges. It was originally hoped that earthquake phase data could be inverted for appropriate 3-D velocity models for this area. However, preliminary analysis of the waveforms archived at the SCEC Data Center indicates that much of the telemetered data at certain critical sites from the western part of the regional network suffer from cross-talk problems, and apparent phase arrival times are subject to large systematic errors. These problems, plus poor azimuthal control and ray coverage, inhibit our ability to resolve 3-D velocity structure, but the data can be used to solve for improved 1-D velocity models using progressive inversion and either exponential (L1) and Gaussian (L2) norm residual minimizations. Owing to the presence of deep sedimentary basins, the resulting mean crustal velocity above 20 km depth is lower than that found regionally for southern California [Hadley and Kanamori, 1977], but is consistent with seismic refraction studies for the western Transverse Ranges [e.g., Keller and Prothero, 1987]. Earthquake arrival-time information, including recently discovered 1984 OBS phase data for earthquake swarms in the Santa Barbara Channel, were then used to relocate earthquakes within this improved 1-D velocity model. The results of the earthquake relocation define a relatively steep (~70°) south-dipping active Oak Ridge fault within the eastern Santa Barbara Channel, as well as seismicity associated with relatively steep south-dipping Santa Ynez and Arroyo Parida-Mission Ridge faults. Additional earthquakes appear to be associated with low-angle north-dipping structures that, at the coast, occur at a depth of 12-14 km, but which tend to steepen farther north.

Relationship between the Dynamic and the Kinematic Parameters of a Seismic Source

Stefan Nielsen and **Leon Knopoff**
University of California, Los Angeles

While a set of analytical relationships between the kinematic parameters of ruptures such as slip rates and crack edge velocities, and the dynamic parameters of the friction law and the stress drop, exists for anti-plane fractures, these relationships do not exist in general for in-plane cases. They have been described analytically only for simplified mathematical models of in-plane cracks under restricted conditions of heterogeneity and geometry. In the anti-plane cases, low stress drops are associated with a drop in rupture propagation velocity and with low slip velocities; this is to be expected intuitively for the in-plane cases as well. In the absence of an analytical framework for the description of complex in-plane ruptures, we have had to rely on numerical modeling to provide some insights into these relationships. We offer the following generalizations, which could be quantified by a systematic exploration. As in the anti-plane cases, heterogeneity in the form of an increasing friction or fracture strength, or as a decrease in the stress drop, slows down the mean rupture propagation velocity. Although the crack tip velocity in a homogeneous region tends to a steady value which can only be the Rayleigh, shear or compressional wave velocities, according to the ratio between static friction or fracture strength and dynamic friction, the crack tip is temporarily slowed down if it encounters a locus of increasing strength; then it again approaches a steady velocity asymptotically; steps and other geometrical irregularities of the fault surface are sites of lower slip velocity and slower crack speeds; the overall inhibition of rupture in terms of a slower crack propagation velocity and a lower slip rate can be due to the effects of changes in the stress drop or the properties of the elastic medium, or due to a continuous change in the geometrical irregularity of a fault, or a superposition of these effects.

Resolution of Site Response Issues From the Northridge Earthquake (ROSRINE), Phase 1 Progress Report

R. Nigbor[1], R. Pyke[2], C. Roblee[3], J. Schneider[4], W. Silva[5], R. Steller[6], M. Vucetic[7]

The ROSRINE project brings together under one umbrella strongly coordinated group of geologists, geotechnical engineers and seismologists from a number of organizations to address geotechnical site characterization and ground motion response issues resulting from the Northridge earthquake. The work is co-funded by the National Science Foundation and the California Department of Transportation (Caltrans), and is heavily leveraged by cost-sharing from the Electric Power Research Institute (EPRI), the Southern California Earthquake Center (SCEC), and the U.S. Geological Survey (USGS), and with cooperation from the California Department of Mines and Geology (CDMG). SCEC serves as administrative coordinator for the various co-investigators.

The objective of Phase 1 of this project is the collection, compilation, and rapid dissemination of high-quality site geotechnical and geophysical data for about 10 key Northridge Earthquake strong motion recording or structural damage sites. Investigations will include geologic and seismic-velocity logs, e-logs, and collection of high-quality samples for laboratory testing in Phase 2. Sites completed to date include Arleta, Kagel Canyon, Pacoima Downstream, Newhall, La Cienega, and Sepulveda, VA.

---

[1]Agbabian Associates, Inc., [2]Consultant, [3]CALTRANS, [4]Impact Forecasting, [5]Pacific Engineering and Analysis, [6]Agbabian Associates, Inc., [7]UCLA

Evidence for Lateral Crustal Variations and a Dipping Interface in the Lower Crust - Analysis of Onshore-Offshore Data from LARSE Line 1 and Line 2

Julie J. Norris and **Robert W. Clayton**
California Institute of Technology

Onshore-offshore refraction-wide angle reflection data from LARSE-94 provides an opportunity to image the crust in the offshore borderland and the tectonically complex Los Angeles region. Two transects with moderate to good quality data (Lines 1 and 2) are analyzed. Line 1 extends from offshore San Clemente Island, through Seal Beach, to northwest of Barstow. Line 2 extends from west of Santa Catalina Island, through Malibu, to the western Mojave Desert.

Data from Lines 1 and 2 show large lateral travel time variations in common receiver gathers that are attributable to the sea floor topography and offshore micro-basin structure. After correcting for these effects, later and weaker phases are revealed. Receivers in the San Gabriel Mountains and the Liebre-Sierra Pelona uplift, directly northwest of the San Gabriel Mountains, exhibit almost no delays due to topography, implying that the crust beneath the mountains is fast.

Line 1 receiver delays for stations in the mountains and desert reveal an interface dipping 5-10 degrees to the north with a lower layer velocity of 7.4 km/sec, possibly indicating the top of an overridden oceanic plate. Line 2 also reveals an interface dipping approximately 10 degrees to the north. Simple models of the regional crustal structure suggested by data from these transects will be presented.

Seismic Profiling across the Northridge epicentral region using LARSE and Industry Data

David Okaya, Tom Henyey, Ryan Smith
University of Southern California
Gary Fuis, U.S. Geological Survey
Tom Wright

Analysis of SCEC/USGS data in and across the Northridge epicentral region progresses. The Larse Line 2 onshore-offshore seismic data contain the fundamental Pg, PmP, and Pn wide-angle seismic phases. A 2-D velocity model will be presented for the transect between Santa Monica basin to the westernmost Mojave desert. The seismic data indicates crustal thickening along this transect. Seismic processing is also underway of the multichannel seismic reflection profile between Malibu and San Clemente Island which is associated with Larse Line 2. Strong water bottom multiples overprint any reflections beneath the basin sediments; no lower crustal or Moho reflections are visible. Sea floor disruptions reveal active faults in the Santa Monica basin and near both Santa Catalina and San Clemente islands. Simple basins do not exist underneath the MCS profile as is demonstrated by irregular basins and basement highs. Upper crustal velocity structure is extended offshore using the results of OBS analysis by ten Brink et al.

Industry data in San Fernando valley provide additional velocity structural information for the basin sediments. Sonic and density well logs were digitized in order to create time-depth curves and synthetic seismograms. These curves indicate that San Fernando sediments are slow (<3.0 km/s at a depth of 2 km). Stacking velocities for selected common depth points also indicate low velocity sediments. Structural interpretation is underway by Wright et al.

3-D Los Angeles Basin Amplification Effects

K. B. Olsen and R. J. Archuleta
University of California, Santa Barbara

We have used a 3-D finite-difference method to simulate 0-0.4 Hz ground motion from hypothetical earthquakes on the Palos Verdes, Elysian Park, Santa Monica, Newport-Inglewood, Oakridge (Northridge), and San Andreas faults near LA. The earthquakes were simulated as elastodynamic propagating ruptures with constant slip on the faults in two different velocity models (115 km by 95 km by 34 km): a 1-D regional (rock) model and one including the 3-D structure of the Los Angeles and San Fernando basins, assembled by Magistrale and others. Ratios of 3-sec 3D/1D root mean square velocity response spectra (5% damping) vary considerably between the scenarios in the LA basin. In particular, the amplification tends to increase with distance from the causative fault to the basin structure. The response spectral ratios for the six scenario earthquakes are combined into an average LA basin amplification map. The LA basin is outlined by an average 3-sec response spectral ratio of 2 with a maximum value of 4.1. The sites associated with the largest mean 3D basin amplification effects are located above the deepest parts of the basin; log standard deviations are less than 1.2. These amplification values are partly controlled by the 3D basin structure, partly by impedance difference effects between the 1D and 3D models.

1D simulations suggest that the impedance difference effects account for about 50% of the amplification. Durations are also significantly increased by the 3D basin structure. The largest 3D-1D durations are obtained for the Santa Monica, San Andreas, and Palos Verdes earthquakes, for sites above the deepest part of the basin.

An Active Structure Beneath Downtown and East Los Angeles, California

Michael Oskin and **Kerry Sieh**
California Institute of Technology

We used subsurface data from the fault investigation for the Eastside Red Line Metrorail Subway in conjunction with detailed topographic maps to investigate two young folds beneath Downtown and East Los Angeles. These are parallel, 2 km-wide, east-west trending anticlines that deform late Pleistocene alluvial surfaces. The surficial expression of the Pomona Freeway anticline is symmetric, 6.5 km long, plunges eastward toward the Montebello Hills and is truncated westward by the Los Angeles River. The Repetto Hills anticline is asymmetric, at least 8 km in length, merges eastward with the Monterey Park Hills, and projects westward across the Los Angeles River, beneath the downtown business district. Along the south limb of the Repetto Hills anticline, fluvial deposits 60-100 ka old are tilted up to 30 degrees across a sharp, 100m-wide monocline known as the Coyote Pass Escarpment. From analysis of bed tilting and thickening, we measure 15m of uplift and 13m of shortening across this monocline. This yields a fold-consumed slip rate of 0.2-0.3 mm/yr and a horizontal convergence rate of 0.1-0.2 mm/yr. Several generations of surface aggradation, deformation, and incision suggest continuing uplift of these structures through the latest Pleistocene. Examples of coseismic fold growth of similar structures at Coalinga and Whittier Narrows lead us to suggest a blind-thrust mechanism of folding may be viable. To hypothesize future near-surface coseismic deformation, we calculated tilting and shortening for a hypothetical 1 m coseismic uplift of the Repetto Hills anticline. Horizontal contraction up to 2.7% and tilting up to 2.4 degrees would accompany such an event about every 4,000-6,700 years. If coseismic uplift were 0.25 m, the corresponding values would be 0.6 percent contraction, 0.7 degrees of tilting, and a recurrence interval of 1,000-1,700 years. The predicted near-surface strain and close proximity of potential fold-associated blind thrust faults represent a significant hazard to the Downtown and East Los Angeles areas.

Crustal Deformation in Southern California and Northern Baja California: Kinematic Estimates from Finite Element Modeling

Randy Palmer and **Gene Humphreys**
University of Oregon

Pacific-North American (PA-NA) relative plate motion is accommodated across southern California and northern Baja California on a complex set of faults. We model the regional kinematics by incorporating plate motion data, fault orientation and slip rate estimates, and very long baseline interferometry (VLBI) baseline length-change data. Using finite element modeling to enforce kinematic consistency (the "compatibility" condition), this model predicts the surface velocity field and fault slip velocity everywhere in northern Baja and southern California. The strain energy created by the specified conditions is used as a "least squares" measure of model goodness.

To quantify uncertainties and to find the kinematic model that is most consistent with the available data, we Monte Carlo sample each of our data parameters 1000 times, keeping track of the net strain energy of each model. (Sampling ranges over the stated uncertainty of each datum.) From the suite of models we find the model that has the minimum elastic strain energy, and we calculate statistics on uncertainties each of the model parameters. This is the kinematic model of minimum kinematic inconsistency under the prescribed constraints, and it provides a back-looking, global measure of the uncertainties.

We present results from four models: 1) a model that is driven solely by VLBI baseline data and the NUVEL plate motion; 2) a model driven solely by fault slip-rate data and the NUVEL velocity; 3) a model driven equally by VLBI and fault slip-rate data and VLBI data; and 4) a model with greater emphasis given to the VLBI data. In an overall sense, the two data sets are consistent, though interesting differences exist.

Quaternary Chronostratigraphic Constraints on Deformation in the Northern Los Angeles Basin, California

D. J. Ponti
U.S. Geological Survey, Menlo Park
J. P. Quinn, Gorian and Associates
J. W. Hillhouse and **C. L. Powell II,** U.S. Geological Survey, Menlo Park

Preliminary lithologic, amino-acid, paleomagnetic, and macrofauna data from continuous cores drilled through Pleistocene sediments at Rancho La Brea, and a densely sampled core hole drilled near the intersection of I-10 and La Cienega Blvd., define several chronostratigraphic horizons that can be used to constrain rates of Quaternary growth of a complex south-verging monocline that occurs along the northern margin of the Los Angeles basin. Recent structural interpretations attribute this fold to activity on one or a combination of several postulated blind-thrust faults, i.e.: the Elysian Park fault, the Los Angeles fault, the Wilshire fault.. Pliocene-Recent vertical deformation rates of nearly 1 mm/year have been proposed. In contrast, our new data imply a vertical deformation rate of >0.34 to ~0.55(?) mm/yr for the time period ~800 ka to present and <0.27 mm/yr for the time period ~300 ka to present. These results suggest that rates of recent fault activity in the northern Los Angeles basin are significantly slower than previously proposed and also imply that the rate of fold growth has decreased through time. In addition, results from the La Cienega hole indicate a rate of tectonic subsidence of ~0.1-0.15 mm/yr for the period 300 ka to present – a condition that is incompatible with detachment-fault models. Finally, we observe that the age of the Q/T boundary, as defined by e-log picks and benthic microfauna biostratigraphy, varies by >450 ka within our core holes. These data thus invalidate, for the Quaternary, an important assumption of structural models that stratigraphic boundaries approximate time-lines.

Correlation Between Observed Seismicity and GPS Derived Aseismic Crustal Deformation Rates in Southern California

David Potter and **David Jackson**
University of California, Los Angeles

This work investigates the correlation between crustal deformation rates and observed seismicity in southern California. The crustal deformation rates calculated at densely spaced grid points is statistically compared to the deformation rates at earthquake epicenters.

The rates of maximum shear, dilation and rotation are derived from the 1996 SCEC velocity map of southern California. The surface displacement rates from the 1995 WGCEP Phase II fault model are removed from the geodetically derived velocity vectors and the statistical correlation of the residuals is assessed using semivariogram theory. The optimally fitted semivariograms form the basis functions for the least squares inversion of the velocity residuals which yields horizontal crustal velocities and deformation rates at a series of grid points. The total crustal deformation rate field is determined by summing the inverted residuals with the Phase II fault model results at the grid locations. Over the same region, crustal deformation rates at earthquake epicenters are determined. The earthquakes are declustered to remove spatial and temporal clustering associated with aftershock occurrence.

The results of the Kolmogorov-Smirnov test indicate that the cumulative distribution functions of the two sets of crustal deformation rate values (seismicity and reference grid) are significantly different. This implies preferential location of seismicity in regions of increased maximum shear strain.

A Research Of The State And Local Laws Relating To The Health And Safety Of Children And How They Relate To Their Legal And Financial Responsibilities

Donna M. Rathman, SCEC Summer Intern
Irvine Valley College
University of California at Irvine

The importance for clearly established lines of responsibility in the event of an emergency needs to be further addressed for children in school. In an emergency situation there is a need for assurance that schools will be responsible for the welfare and security of children. Without a clear definition of the programs and their funding there is no clear definition as to the responsible party. Therefore, children's health and safety may fall through the cracks. This project will research various codes, regulations, and policies effecting the educational system. All codes are categorized into three sections; mandatory planning, preparedness measures, and disaster response. The codes are then reflected in the hierarchy of the educational system. There is a need for more implementation and monitoring of codes at the school and district level. Because there is no monitoring system for the implementation of these codes at the local level, there is no assurance that minimal health and safety procedures are in effect at the school sites. In the state of California, all state agencies are required to respond to emergencies by use of the Standardized Emergency Management System (SEMS). While schools are considered state agencies, the chain of command within the education system is complex and therefore is not easily incorporated into the SEMS.

Seismic Constraints on Fault Strength and Toughness

James R. Rice
Harvard University

If the breakdown process at the advancing front of an earthquake rupture is interpreted as a slip-weakening process, then the fracture energy G_{crit} associated with it provides a constraint on the product $(\tau_{peak} - \tau_{dyn})$ L. Here τ_{peak} is the peak shear strength to initiate sliding, τ_{dyn} is the strength at which large dynamic slip takes place, and L is a characteristic slip in a parameterization of weakening proportional to exp(-slip/L). The data on self-healing ruptures assembled by Heaton (*PEPI*, 1990) leads to $G_{crit} = 0.3$ to 4.8 MJ/m^2, with average 1.9 MJ/m^2, for seven large events. On the other hand, if we know the minimum rupture patch diameter, D_{min}, on which earthquakes occur with the same range of large stress drops as for events on larger patch areas, then from critical stiffness arguments we can estimate $(\tau_{peak} - \tau_{dyn}) / L$, and hence solve for each weakening parameter separately: $\tau_{peak} - \tau_{dyn} = 1.66 (\mu G_{crit} / D_{min})^{1/2}$ and $L = 0.60 (G_{crit} D_{min} /\mu)^{1/2}$, where μ is the shear modulus. We have no data on D_{min} from the sites of Heaton's events, but the Abercrombie and Leary (*GRL*, 1993) data from 2.5 km depth recording in the Cajon Pass borehole suggests $D_{min} = 25$ m. Using such value, one obtains $\tau_{peak} - \tau_{dyn} = 300$ to 1250 bars for the seven events, with average 725 bars, much higher than the 23 bar average dynamic stress drop. Nominal friction coefficients f can be defined by dividing each strength τ by the average of overburden minus hydrostatic pore pressure over the depth range of faulting; thus $f_{peak} - f_{dyn} = 0.25$ to 0.80, with average 0.50. The inferred values of L range from 10 to 40 mm with average 22 mm, and are consistent with strength loss by shear heating of a fluid-infiltrated fault gouge if, in the Lachenbruch (*JGR*, 1980) analysis of that process, we assume a deforming fault zone of order 3 to 12 mm thickness. The results suggest that major faults generally have the high strength expected from lab friction studies, but can operate at low overall driving stress because they also have low toughness in rapid slip.

Estimating Crustal Thickness in Southern California by Stacking PmP Arrivals

Keith B. Richards-Dinger and **Peter M. Shearer**
University of California, San Diego

We use observations of the Moho reflected phase PmP to constrain crustal thicknesses and upper mantle velocities in southern California. Our analysis uses over 360,000 seismograms from 4625 local events recorded by the USGS/Caltech Southern California Seismic Network (SCSN) and available through the Southern California Earthquake Center (SCEC). We stack the normalized absolute values of the seismograms in time and range bins after aligning on the initial P arrival and applying a range correction to adjust the various source depths to the surface. Although most individual seismograms do not allow accurate determination of a PmP arrival time, imaging the whole dataset in this way shows clear PmP arrivals at ranges from about 90 km to over 250 km. PmP-Pg and PmP-Pn differential times can be measured from the image and used to estimate the Moho depth and upper mantle velocity. Assuming a reference crustal velocity model, we perform a grid search over crustal thickness and mantle velocity to minimize the 1-norm of the misfit between the predicted and observed PmP-P differential travel times. For southern California, we obtain an average crustal thickness of 28 km and an upper mantle velocity of 7.8 km/s. Next, we repeat this procedure for stacks of subsets of the data, in which the traces are grouped in caps by Moho reflection point. PmP can be identified for the majority of these caps, permitting the mapping of lateral variations in crustal thickness and upper mantle velocity. Estimates of Moho depth range from 18 km in the Salton Trough to 33 km beneath the eastern Transverse Ranges, to 36 km beneath the southernmost Sierra Nevada. The upper mantle velocities generally increase from southwest to northeast across the region. These results are robust with respect to upper crustal velocity variations, since these cause similar time shifts to both P and PmP. However, the estimates are sensitive to the assumed lower crustal P velocity of 6.7 km/s. We also use these seismograms to map post-critical PmP/Pg amplitude variations; these amplitudes vary by a factor of 4 with the highest amplitudes in the northwest Mojave Desert. Preliminary experiments with stacking SmS arrivals indicate spatial variations in SmS amplitudes that are strongly correlated with the PmP amplitudes. Since these are post-critical reflections the observed variations cannot be produced by differences in the Moho reflection coefficient and presumably result from focusing and defocusing effects caused by Moho topography and/or crustal heterogeneity. These results provide a guide to source-receiver paths that may produce anomalously strong Moho reflected phases during future earthquakes.

NON-LINEAR, HARD SPRING EFFECTS IN GEOPHONES

Peter W. Rodgers and **Aaron J. Martin**

University of California, Santa Barbara

Experimental data are presented which show that some commonly used horizontal geophones become non-linear when mis-leveled by less than one half degree of tilt. This non-linearity is attributed to the geophone spring. We have modeled the non-linear spring as a "hard" spring of the form:

$$F(z) = k(1 + \beta^2 z^2)z$$

The resulting equation of motion is non-linear and is known as an inhomogeneous Duffing's equation:

$$\frac{d^2z}{dt^2} + 2\zeta\Omega\frac{dz}{dt} + \Omega^2 z + hz^3 = -\frac{d^2x}{dt^2}$$

Solutions to this non linear equation are compared with the experimental results obtained using a Mark Products L-4C horizontal geophone.

Earthquake Activity of the Sierra Madre Fault, Altadena, California

Charles Rubin
Central Washington University
Scott Lindvall
Harza Engineering Company
Tom Rockwell
San Diego State University

A trench excavated into the scarp of the Sierra Madre fault at Loma Alta Park in Altadena revealed stratigraphic evidence for two earthquakes. Two scarp-derived colluvial wedges were recognized overlying a buried soil. Restoration of dip slip along the fault indicates a minimum of ~3.8 - 4.0 m of slip from the most recent earthquake. Palinspastic restoration of the paleosurface, represented by the buried soil, with the geomorphic surface above the scarp on the hanging wall yields a total cumulative slip of ~10.5 m. Based on stratigraphic evidence from trench wall exposures, this slip was apparently produced by only two events. This implies that the average slip at this site may have been as much as 5 m in each of the past two earthquakes.

We have attempted to resolve the timing of these events using soil chronology and radiocarbon dating. Comparing soil development index (SDI) and maximum horizon index (MHI) values of the soil, exposed in a pit on the fan surface above the scarp, with other known dated soils developed in southern California, we estimate the age of the offset surface to be ~ 8 ka.. If both events occurred since 8 ka, our observations would suggest that this segment of the fault fails in large earthquakes on average every four to eight thousand years.

Precise accelerator mass spectrometer ^{14}C dating of detrital charcoal collected from the colluvial and alluvial units exposed in the footwall exposures and in unfaulted colluvial units in trench wall exposures were analyzed at the Accelerator Mass Spectrometer Laboratory, University of Arizona. Detrital charcoal fragments collected from Unit 4a, the coarse-grained colluvial deposit representing the colluvial wedge produced following the most recent earthquake, yield ages ranging from 8965 B.C. to 15,235 ^{14}C yrs B.P. This suggests long residence of detrital charcoal in the system; these dates therefore represent the maximum age of the deposit. Similarly, radiocarbon samples in Unit 3 range in age from 15,600 to 34,300 ^{14}C yrs B.P. and samples from Unit 2 range from 15,600 to 29,900 ^{14}C yrs B.P. These broad ranges of ages reflect reworking and recycling of detrital charcoal fragments from older stratigraphic units. Because of the reworking of detrital charcoal, we prefer the interpretation that these two events occurred in the last 8 ka, based on the estimated age of the offset surface from soils. This is consistent with about a 1 mm yr^{-1} slip rate estimated from uplifted late Pleistocene fan surfaces on the hanging wall.

INFLUENCE OF LOS ANGELES BASIN STRUCTURE ON GROUND MOTIONS FROM A Mw 7.9 SCENARIO SAN ANDREAS EARTHQUAKE USING 2-D RELATIVE SITE TRANSFER FUNCTION TECHNIQUE

Chandan K. Saikia
Woodward-Clyde Federal Services

The objective of this study is to apply two-dimensional relative site transfer function method to assess how 1-D ground motions simulated at some selected sites within the Los Angeles basin from the San Andreas scenario earthquake are modified when the influence of basin structure is included. To map the effects of 2D response onto the 1D simulation, we convolved 1D ground motion time histories with the relative site transfer functions (RSTF) computed between a reference site located nearly at the edge of the profile and the selected sites. We selected different RSTF responses representing the 2D path effect for different portions of the fault. Attempts were made to establish the reliability of this method by comparing the ground motion amplification with the value computed using the full 3-D calculation at longer periods. The method seems to predict similar amplifications for ground motions recorded during the Landers earthquake at Downey which is located in the deepest part of the Los Angeles basin relative to a neighboring basin edge site at Obregon Park. The RSTF method is useful because it can be used to predict high frequency ground motions as its finite-difference/irregular basin response calculation does not require a large memory compared to a full 3D calculation. It also handles low velocities in the model. In addition, it avoids running time-consuming finite-difference algorithms repeatedly for different slip realizations as the latter is part of the 1D simulations.

Surface Wave Amplitudes in the Los Angeles, California Region

Craig W. Scrivner and **Donald V. Helmberger**
California Institute of Technology

The K2 strong motion network in southern California consists of instrument packages with a 3-component FBA and a short-period vertical sensor. The package has broader frequency bandwidth and larger dynamic range than the existing USGS/Caltech network. Because of these improvements, surface waves are recorded in basin structures for moderate earthquakes in southern California. The 1995 Ridgecrest earthquake sequence triggered the first recordings by the K2 network. At that time there were K2 stations in the San Bernardino, San Gabriel, and Los Angeles basins. We have compared surface waves recorded by the K2 array with those recorded elsewhere in southern California by TERRAscope. Zhu and Helmberger (1996) inverted TERRAscope waveforms to determine source parameters for 335 earthquakes in southern California. They base their inversion on a standard 1D model of the southern California crust. We use the source parameters for the three largest Ridgecrest events and the 1D model to generate synthetic waveforms for the K2 and TERRAscope stations. In the 5 to 10 second period band, the maximum amplitudes of the K2 data are fit by the 1D synthetics almost as well as the TERRAscope data are. The maximum data amplitudes from both arrays are generally within a factor of 2 of the synthetic amplitudes. These amplifications are less than expected (i.e. Olsen et al., 1995). Near nodes in the surface wave radiation patterns, the data amplitudes tend to be much larger than the synthetic amplitudes. TERRAscope data follow the nodes more closely than K2 data. There are also some amplifications at shorter periods, but not as large as expected.

Tectonic Implications of the Southern California Earthquake Center Crustal Deformation Velocity Map

Zheng-kang Shen, David D. Jackson, Li-yu Sung, David Potter, and Bob X. Ge
University of California, Los Angeles

Using GPS and EDM data, the SCEC Crustal Deformation Working Group (this meeting) derived secular station velocities at 287 sites in southern California. The SCEC "Phase II" fault model explains most of the secular deformation, nevertheless there are still significant systematic residuals. They are: (1) An excessive dextral shear centers on the San Jacinto fault. (2) Stations north of the 34-degree latitude show residual northwest motion. (3) Dextral deformation across the Mojave section of the San Andreas is broader than predicted by Phase II model. (4) Only a small fraction of the 6 mm/yr NNE convergence across the Los Angeles basin is described by Phase II model. (5) The Landers earthquake apparently caused more than 10 mm/yr postseismic deformation in the central Mojave desert.

Shear strain rates are largest along the Imperial fault and at the epicentral area of the Landers earthquake (about 0.4 micro-rad/yr). About 0.2 micro-rad/yr of shear strain are also detected along the Carrizo section of the San Andreas, the White Wolf, part of the Mojave section of the San Andreas, the San Jacinto, the Coachella section of the San Andreas, and the Ventura Basin. Geodetic strain rates seem to mimic the historical seismic strain pattern in southern California in general, suggesting either earthquakes occur at regions of high strain rates, or post-seismic deformations are significant and long-lasting, or both.

Post-Miocene Strike-Slip Along the Southern Hosgri Fault System, California, Determined From Map Restoration

C. C. Sorlien[1,2], M. J. Kamerling[1], and D. Mayerson[3]
1=University of California, Santa Barbara, CA
2=Lamont-Doherty Earth Observatory of Columbia University
3=Minerals Management Service, Camarillo, CA

The Hosgri fault is the southern part of the San Gregorio-Sur-San Simeon-Hosgri fault system, an important element of the Neogene California transform system. The NNW-striking Hosgri fault has been inferred to be a thrust fault or a strike-slip fault which is truncated against or merges with the E-striking faults of the Transverse Ranges. We correlated several late Miocene through Quaternary sequence boundaries throughout an area of 2000 km^2 at the southern end of the Hosgri fault system, using 3000 km of multichannel seismic reflection data, 77 offshore exploratory wells, coastal geology, and published subsurface oil field maps. Our structure-contour maps of the top of the Sisquoc Formation and an early Quaternary horizon were digitized and restored to horizontal using the software UNFOLD. Displacements are calculated by comparing the restored surface to the present state with respect to a relatively-fixed line. A 3-D perspective view of the top Sisquoc map shows fold patterns that are consistent with the Hosgri fault being predominantly a right-lateral strike-slip fault. Right-stepping en-echelon folds west of the Hosgri fault and a NNW-trending fold adjacent to and parallel to that fault represent 1-4% shortening (up to a few hundred m). Shortening of the same blocks has been 0.15-1.36% since deposition of the Quaternary map horizon. Shortening is higher east of the Hosgri fault, with areas near Pt Conception, Pt. Pedernales, and Pt. Sal shortened by 8, 10, and 15%. However, the resulting folds trend at a high angle to the Hosgri fault, and thus absorb right-lateral strike-slip. Shortening is greater across these folds at the coast than adjacent to the Hosgri fault, which indicates a clockwise rotation of fault-bounded small blocks. Minor right-stepping en-echelon fault strands die into these folded, rotating blocks. The sense of vertical separation across the Hosgri fault changes along strike and is different for different horizons. Normal separation of mid Sisquoc horizons across the moderately E-dipping main strand occurs along most of the fault, except near Pt. Sal. The average rate of right-lateral displacement at 35° N since 5 Ma is 0.6 mm/yr across the Hosgri fault, but displacement of a point 20 km east of the fault is 1.0 mm/yr due to clockwise rotation north of the N-dipping Lion's Head fault.

Our region correlation of sequence boundaries extends to the western end of the N-dipping backlimb of the 220 km-long Santa Monica Mountains-Channel Islands anticlinorium. Initiation of progressive tilting of a 10 to 20 km wide (down-dip direction) fold limb is dated by onlap onto a sequence boundary that formed about the end of Pliocene time. Our restoration now overlaps that of Sorlien and others, and Gratier and others, so there now exists a continuous restoration from Los Angeles basin through offshore Santa Maria basin.

CONSTRAINTS ON THE UPLIFT OF THE SAN BERNARDINO MOUNTAINS USING PRE-UPLIFT WEATHERING SURFACES AND APATITE HELIUM THERMOCHRONOLOGY

James A. Spotila, Kerry Sieh and **Ken Farley**
California Institute of Technology

The geologically recent uplift of the San Bernardino Mountains represents a significant episode in the tectonic evolution of the Transverse Ranges and the San Andreas fault. However, there is yet no firm understanding of the kinematic relationship between this uplift and the horizontal motion along the plate boundary, nor of the geometry and nature of the active structures accommodating this motion. We attempt to quantify the amount and timing of uplift with two methods, in order to better understand these problems.

We have identified the distribution of a weathering surface in order to place some constraint on the vertical motion on uplifting structures. This feature has been previously postulated to be pre-uplift based on several observations, which we are in the process of evaluating. If this feature did form prior to uplift and if assumptions can be made about its original geometry, then a comparison of its distribution within and outside of the mountain can lead to an assessment of the vertical displacement that has occurred. We present one possible reconstruction of this weathering surface and compare it to the geometries of the North Frontal fault zone and the Santa Ana thrust, both of which have been previously suggested to have uplifted the main block of the range.

We are also in the process of measuring (U-Th)/He ages on apatite separates from granitic rocks within the range. These ages are sensitive to low temperatures due to the retention of He in apatite, with a "closure temperature" of 75 degrees C for a 10 degrees C/Ma cooling rate. These ages can identify recent large uplift, or be used to create a "stratigraphy" of isochrons that can constrain the relative uplift of range blocks. Preliminary results seem to constrain the relative amount of uplift between the Big Bear plateau and the San Gorgonio massif, and suggest very recent uplift of the southernmost San Bernardino mountains.

Consistent Models of Site Response Which Include Ground Motion at all Input Levels

Jamison H. Steidl, Luis Fabian Bonilla, Alexei G. Tumarkin, and **Ralph J. Archuleta**
University of California, Santa Barbara

Very often site response studies in the same region can be inconsistent or almost impossible to compare with each other due to differences in the techniques used. It is important to be able to combine the different studies (geological, geotechnical, and seismological) in a consistent way to produce a site response model that will be useful for practical application to seismic hazard assessment, engineering design, or urban planning. In this study we are developing consistent site response models which use empirical data (both weak- and strong-motion), geologic and geophysical parameters, strong-motion attenuation relations, and analytical (geotechnical) models.

Two independent empirical weak-motion site response studies in Southern California are combined using consistent site classifications to examine correlations between site response and geological and geotechnical parameters. The site classifications are determined using geological and geotechnical parameters that are relevant to those used in attenuation relations and regulatory codes. The empirical weak-motion results are compared with site response estimates which use strong-motion data in Southern California, and analytical estimates of site response which contain nonlinearity at high input levels of ground motion. The weak-motion studies compare well with the low input level strong-motion results. This multi-disciplinary approach has been useful in determining where improvements to our models can be made and what new measurements are needed.

Progress on Refining High-Resolution Seismic Imaging as a Tool for Paleoseismic Studies

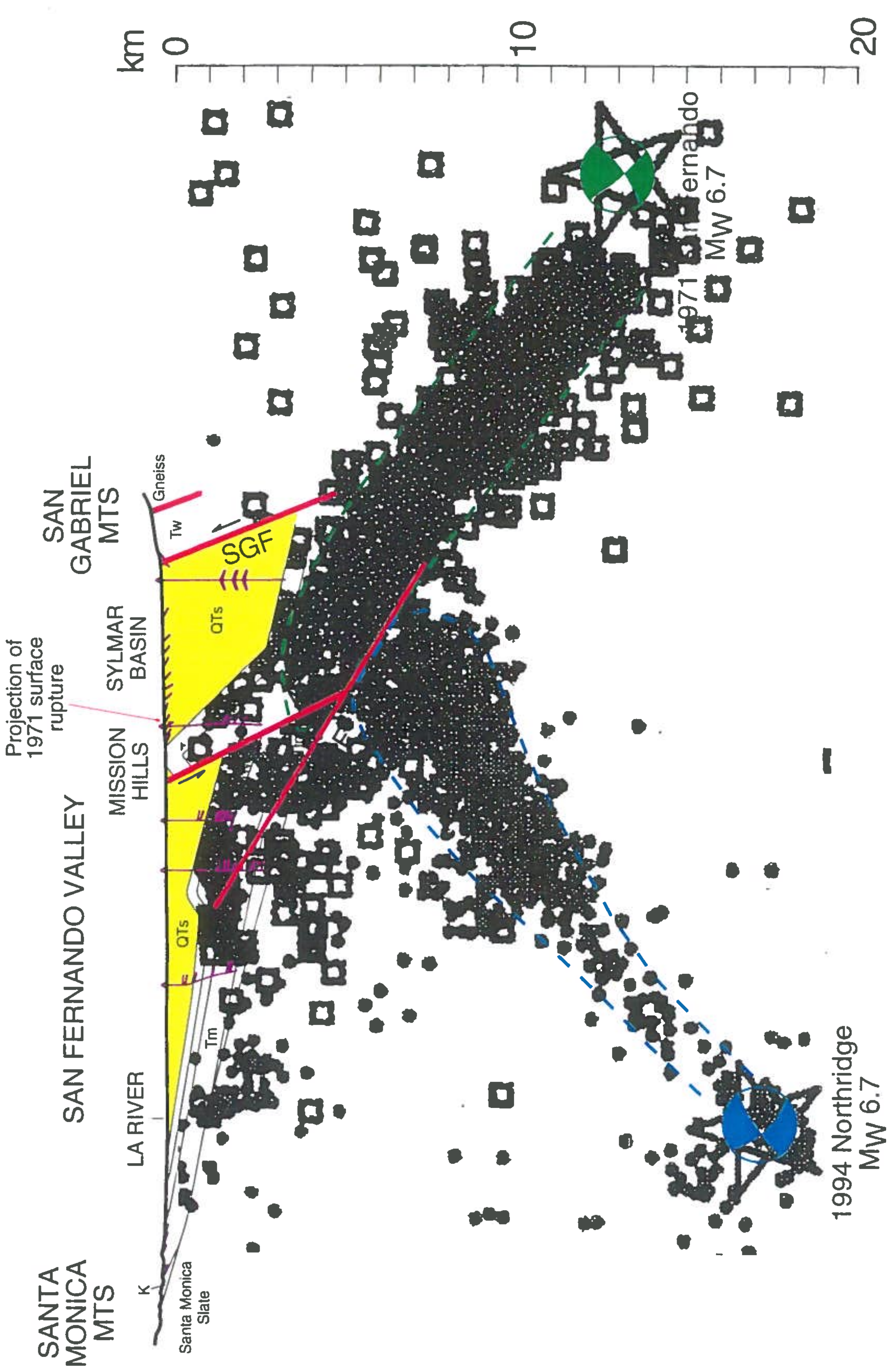
Mary E. Templeton and **De Ann Icenogle**
California State University, Fullerton

Velocity analysis and correlation of coincident P and S wave reflections in the San Jacinto Graben show that S-wave data imaged shallower, thinner features than P-wave data at this site. The shallowest features on P-wave images are approximately 20 meters deep, while S-waves began imaging reflectors at 4 to 9 meters. Both profiles show reflectors at 20 and 108 meter depths. Sediments above 20 meters had V_p/V_s ratios ranging from 6 to 8. S-wave data have a lower signal-to-noise ratio than the P-wave data, yet shallow S reflections show more vertical detail after depth migration.

NEW GEOLOGICAL MODEL OF THE 1971 SYLMAR EARTHQUAKE (Mw 6.7) BASED ON SEISMIC AND WELL DATA FROM THE SAN FERNANDO VALLEY, CALIFORNIA

Hiroyuki Tsutsumi
Kochi University, Japan
Robert S. Yeats
Oregon State University

We combine oil-industry well and seismic data with aftershocks of the 1971 and 1994 earthquakes relocated by Mori et al. (GRL 22:1033-1036, 1995) to derive a new structural model for the 1971 earthquake (see figure next page). The 1971 aftershocks merge updip with the Northridge Hills thrust, which brings Miocene-Pleistocene strata southward over thin sedimentary cover of the southern San Fernando Valley. The Northridge Hills thrust is blind, but it has tectonic geomorphic expression in the low, discontinuous Northridge Hills between Devonshire and Nordhoff streets from the San Diego Freeway west to Reseda Boulevard (K. Shields, MS thesis, Ohio University, 1977). A seismic line shows that the Northridge Hills thrust locally forms a decollement between Miocene strata and the north-dipping top of basement. The Northridge Hills anticline is a thin-skinned structure with a growth triangle on its south limb. It was initiated sometime during the deposition of the Saugus Formation, which took place from 2.3 to 0.6 Ma. A hangingwall splay of this fault reaches the surface as the Mission Hills fault, which extends along the southern margin of the Mission Hills at the intersection of the San Diego and Golden State freeways. Still farther north, the Santa Susana fault may be a still higher splay of the Northridge Hills fault that was not reactivated in 1971. The Northridge Hills and Mission Hills faults merge eastward with the Verdugo fault at the



SANTA MONICA MTS
K
Santa Monica Slate
SAN FERNANDO VALLEY
LA RIVER
Tm
QTs
MISSION HILLS
Projection of 1971 surface rupture
SYLMAR BASIN
QTs
SAN GABRIEL MTS
SGF
Tw
Gneiss
km
0
10
20
1971
Mw 6.7
1994 Northridge
Mw 6.7

southwestern margin of the Verdugo Hills near the Golden State Freeway. Surface ruptures follow bedding on the south limb of the Mission Hills syncline and its eastern continuation, the Merrick syncline. We suggest that the surface ruptures are secondary faults related to flexural-slip folding of the syncline and are not the surface expression of the primary fault. This model implies that both the 1971 and 1994 earthquakes ruptured blind reverse faults.

Mid- and Upper-Crustal Structure of the San Gabriel Mountains: Results from Explosion Data from the Los Angeles Region Seismic Experiment (LARSE), Southern California

T. Ryberg
GeoForschungs Zentrum, Potsdam, Germany/U. S. Geological Survey, Menlo Park
G. S. Fuis, U. S. Geological Survey, Menlo Park
W. J. Lutter, University of Wisconsin
D. A. Okaya, University of Southern California

During the Los Angeles Region Seismic Experiment (LARSE), 62 explosions, from 20-2000 kg, were fired along a line extending northeastward from Seal Beach, CA, to the Mojave Desert, crossing the San Gabriel Mountains (SGM). These explosions were recorded by a stationary, linear array of 640 seismographs. Shots and receivers were spaced most densely through the SGM for the purpose of obtaining both a reflection and refraction image of the crust in that area (1000-m spacing for shots and 100-m spacing for receivers).

A stack of common-midpoint (CMP) data (maximum fold, 40) reveals a bright reflective zone, 1-s thick, that dominates the stack and extends throughout most of the mid-crust of the SGM. The top of this zone bends downward from 6-s (~18-km depth) beneath the southern SGM to 7-s (~21-km depth) beneath the northern SGM at a point vertically below the surface trace of the San Gabriel fault. Farther north, this zone becomes less bright and also bends downward slightly (0.5 s) at a point vertically below the San Andreas fault. (One or more thin (0.2-s thick) reflective zones immediately above this bright zone mimic its shape.) At 5 s (~15-km depth), a subhorizontal, diffuse reflective zone in the Mojave Desert extends southward into the SGM crossing the deep vertical projection of the San Andreas fault without offset but with a change in character to a thin, sharp zone. In the northern SGM, earthquake hypocenters (projected from 15 km on either side of the profile) do not extend below this 5-s reflective zone; in the southern SGM, they do not extend below the 6-s, bright reflective zone. The top of the bright reflective zone, if projected southward, would lie at the base of the Whittier Narrows earthquakes; its top may represent a decollement.

In the uppermost crust, shallow reflections are seen that terminate at the first-arrival branch at a couple of fixed locations along the profile. Ray tracing of these arrivals reveals (1) a reflector that can be traced northward from the Sierra Madre fault trace at a ~20-degree dip to 2- to 3-km depth and (2) a reflector that can be traced southward from the Vincent thrust fault trace at a ~20-degree dip to about 3-km depth. A shallow dip matches well the inferred southward dip of the Vincent thrust fault, but a moderate dip (~50 degrees) would better match aftershock alignments on at least one nearby branch of the Sierra Madre fault zone.

Differences in Probabilistic Ground Motions for Three Seismic Hazard Models of Southern California

Mark W. Stirling and **Steven G. Wesnousky**
University of Nevada, Reno

We illustrate differences in estimates of seismic hazard for southern California resulting from the three models presented by Wesnousky (1986), Ward (1994), and Frankel et al. (1996). Different methods and assumptions were used to develop each model. Wesnousky

(1986) used slip rate and paleoearthquake data to calculate earthquake recurrence rates. In contrast, Ward (1994) used geodetic data to calculate earthquake recurrence rates, and Frankel et al. (1996) incorporated both geologic and historical seismicity data into their model. Wesnousky limited all seismicity to mapped faults, whereas both Ward and Frankel et al. allowed earthquakes to occur away from mapped faults. We have digital versions of the hazard map matrices for the three models. With these data, we have produced maps showing peak ground acceleration at 10% probability in 50 years for each model, and maps of the differences in peak acceleration between them. These differential maps reveal discrepancies of up to 0.5g. The larger differences tend to occur along major faults, in areas characterized by high historical seismicity rates, and in some offshore areas. Some of these differences are clearly due to the choice of attenuation relationship and magnitude-frequency distribution in a model, and whether or not historical seismicity data are used. The choice of methodology therefore has a significant impact on the estimates of regional seismic hazard for southern California at this time, and it is important to find ways to understand and reduce the uncertainties that these differences demonstrate.

References: Frankel, A., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E., Dickman, N., Hanson, S., Hopper, M. 1996. National Seismic Hazard Maps. USGS. Open File Report 96-532.

Ward, S.N. 1994. A multidisciplinary approach to seismic hazard in southern California. Bulletin of the Seismological Society of America 84, 1293-1309.

Wesnousky, S.G. 1986. Earthquakes, Quaternary faults and seismic hazard in California. Journal of Geophysical Research 91, 12587-12631.

Efficient Ground Motion Modeling Using Empirical Green's Functions

Alexei G. Tumarkin and **Ralph J. Archuleta**
University of California, Santa Barbara

Observations of small earthquakes at a site can be successfully used to explain recorded ground motions as well as to predict time histories from a future large earthquake. We developed a very efficient method that fully exploits the major asset of empirical Green's functions representing the whole path propagation effects from the seismic source up to the location of the recording instrument. The idea is to simulate the input motions at the base of the soil column at a site, and then propagate them using an observation of any earthquake at the same site. This concept is widely used in earthquake engineering where the propagation is performed numerically using a geotechnical model of the subsurface media. If one has a seismic record at the site, then the necessity of a detailed knowledge of the subsurface geology is eliminated. The computational procedure has the following steps. A large earthquake is modeled as a heterogeneous kinematic source in a homogeneous space (Aki and Richards, 1980; Spudich and Archuleta, 1987). The waves are propagated up to a certain depth determined by the regional velocity structure. Then we repeat the same modeling process for an observed earthquake. By comparing the observed waveforms with the corresponding synthetics we obtain an empirical site-specific transfer function which describes the propagation of seismic waves from the base to the surface. This transfer function is then applied to initial synthetic predictions of the large earthquake.

Strong Motion Database SMDB on the Web

Alla Tumarkin, Alexei Tumarkin and **Ralph Archuleta**
University of California, Santa Barbara

We are reporting on the progress in establishing the World Wide Web version of SMDB. SCEC strong motion database SMDB contains information about 93 earthquakes, 567 stations and 3182 components of acceleration. It is used by scientists and engineers from 59 institutions and 12 countries. We have implemented the Oracle database engine that provides a considerable gain in the database query performance. Also we are showing the present state of Web applications development.

Geologic Information System for Seismic Hazards of the Santa Barbara Fold Belt

David W.Valentine, Larry D.Gurrola, Ross D. Hartleb, and **Edward A. Keller**
University of California, Santa Barbara

Seismic sources (faults and folds) for the Santa Barbara Fold Belt are the basis for a seismic hazards information system. Our system consists of digital geologic fault and fold maps linked to a relational database system allowing users to find the basic documentation on the seismic hazard for a seismic source. This documentation includes the seismic source characteristics (structure name and type, slip rate class, and timing of most recent movement), and the descriptions, comments and citations on seismic hazard studies (recurrence, slip rates, location) associated with a possible seismic source. Our digital seismic source maps include source and scale information which allows for the geologic information system to include information from site specific to regional studies.

The database is a superset of guidelines outlined by Haller, Machette and Dart (1993). We have extended the guidelines to document folds as a seismic hazard and to allow users to document multiple studies for each 'segment'. Studies documenting specific characteristics, such as slip rates, recurrence, fault dip, are documented individually. Individual records allow for users to update the seismic information incrementally; new studies can be added while preserving information about previous studies. Importantly, our seismic hazards information system can prevent the loss of information by allowing users to document both past and future information studies. A web version is also available at: http://www.geol.ucsb.edu/workgroups/sbhazards/scec_short_1996.html

REFERENCE

Haller, K. M., Machette, M.N., and Dart, R. L. 1993. Guidelines for US Database and Map: June, 1993. USGS Open file Report, 93-338.

FINITE-FAULT, 3D FINITE-DIFFERENCE MODELING OF THE LANDERS EARTHQUAKE

David J. Wald
U.S. Geological Survey, Pasadena
Vince Quitoriano, California Institute of Technology
Robert Graves, Woodward-Clyde Federal Services

The 1992 Landers earthquake provides an good set of strong motion data to study the long-period excitation of the Los Angeles Basin and its sensitivity to both earth structure and source parameterization. We are using a numerical modeling approach to make a systematic study of the importance of a variety of source and propagational effects on the estimation of ground motions produced during the Landers event. As a calibration of the 3D FD finite-fault implementation, we first reproduced the time histories of Wald and Heaton (1994) for their three-fault, variable-slip, source model using their same source and 1D velocity structure. We then analyzed how variations and earth structure affect the waveform amplitudes and fit to the data. Analyses of recorded ground motions for station profiles across the basin indicate peak displacements at sites in the central basin are 3-8 times larger than sites at comparable distances located outside the basin. The general ground motion characteristics are matched by the 3D simulations, although the predicted amplification ratio is smaller and the spatial variability is less than that observed.

WORLD-WIDE-WEB GROUND MOTION MAPS AND FINITE-FAULT MODEL REPOSITORY

David J. Wald
U.S. Geological Survey, Pasadena
Matthew Bachmann and **Vince Quitoriano**
California Institute of Technology

We have constructed a World Wide Web site to provide digital slip models and maps of strong ground motions for important California earthquakes. Specific earthquakes can be interactively selected by epicenter or name, and each has individual pages that include source information, maps of strong ground motion overlayed on high-resolution topography, slip maps, peak acceleration maps, rupture movies, and pointer to related web pages. Further, each earthquake has a pointer to available slip models that have been provided by a variety of researchers. For each, the reference is given (linked if available on the WWW), an image of the model is provided, and the viewer can download the image as well as a digital representation of the rupture model. The file containing the rupture model contains all necessary information recreate the model in space and time, and therefore to use in a variety earthquake studies including, but not limited to, ground motion modeling, stress loading, and engineering analyses. The URL location is: http://www-socal.wr.usgs.gov/slipmodels.html

RAPID PEAK ACCELERATION MAPS FROM THE SOUTHERN CALIFORNIA NETWORK

David J. Wald
U.S. Geological Survey, Pasadena
Vince Quitoriano, California Institute of Technology
Doug Given, U.S. Geological Survey, Pasadena
Phil Maechling, California Institute of Technology

We are providing rapid (< 10 minutes) peak ground acceleration contour maps on top of high resolution topography on the World Wide Web for earthquakes of magnitude 4.0 and larger. A first motion focal mechanism is also provided. The map is interactive in that one can obtain earthquake parameters and station amplitudes by pointing to and choosing the epicenter or station of interest on the map. The contour map is dynamic in the sense that the size, scale, contour interval and topographic resolution are dependent on the earthquake magnitude. Currently uncorrected accelerations are contoured. We are also testing algorithms for providing site and data-gap corrected maps. For larger events we also plan to contour peak velocity. The URL is: http://www-socal.wr.usgs.gov/pga.html

Escape Tectonics in the Northern Los Angeles Region; Evidence from Strain Gradients along the Sierra Madre Fault Zone and Associated Structures

Christian Walls, John Pfanner, and **Thomas Rockwell**
San Diego State University

Recent GPS measurements suggest 6-8 mm/yr shortening between USC and JPL in the greater Los Angeles area. We present new work that shows that this strain is not accommodated solely by shortening on thrust systems such as the Sierra Madre fault zone, Verdugo fault and Santa Monica fault zone. We present here the results of new mapping, geomorphic analysis, and trenching, combined with the previously collected body of data for this region, to develop a pure shear escape tectonic model for the northern Los Angeles basin. This model explains both the high shortening rates as well as the lower than expected slip rates that we are finding on the principal thrust faults, with much of the shortening accommodated by conjugate strike-slip faulting.

The Sierra Madre fault zone represents the frontal fault system of the San Gabriel Mountains in the east-west trending central Transverse Ranges structural province. The thrust fault zone, including the Cucamonga strand, is comprised of several thrust fault segments that extend 100 km westward from Lytle Creek to the San Fernando Valley. Several oblique left lateral faults splay from the main Sierra Madre thrust system, including; the Raymond, Walnut Creek and San Jose faults. The Verdugo fault has a large thrust component with an unknown lateral component and parallels the main thrust system at the western end of the Sierra Madre fault zone.

Detailed soil studies and geomorphic mapping during this previous year show that the Sierra Madre thrust system has actively deformed late Pleistocene to Holocene alluvial surfaces. Ages of alluvial surfaces are estimated using statistical correlation of soil indices to radiocarbon dated soils. We use the ratio of scarp height to the estimated alluvial surface age to determine vertical separation rates along the Sierra Madre fault zone. Our study combined with results of Lindvall et al. (1995) and Matti et al. (1987) reveal a decrease in vertical separation rates along the Sierra Madre fault zone from east to west.

Based on the 36 m cumulative scarp height across three strands that cut the 13,000 year old Qya_1 surface, the Cucamonga segment has a vertical separation rate of ~3.0 mm/yr (Matti et al., 1987), the highest rate along the Sierra Madre fault zone. This vertical separation rate generally agrees with other ratios of scarp height to surface age along the Cucamonga segment from this years study.

Fifty km west of the Cucamonga strand at Altadena, north of the Raymond and Verdugo faults, the vertical separation rate across the active strands is 0.2-0.6 mm/yr, based on scarp height to surface age ratios (Qt6 - 4m/6.8 ka = 0.58 mm/yr; Qt7 - 25m/148 ka = 0.17 mm/yr; Qf8 -38m/164 ka = 0.23 mm/yr). Along the 1971 rupture in the northern San Fernando Valley, an ~1.0 mm/yr vertical separation rate is derived from scarp and surface age ratios of two terraces (Qt4 - 20m/25 ka = 0.8mm/yr; Qt3 - 10m/11 ka = 0.9 mm/yr).

Range front sinuosity and fluvial morphology further reinforce the inference of variation in strain along strike of the Sierra Madre fault zone. Under Bull's (1978) relative tectonic activity classification of mountain fronts (classes 1-5; 1 being the most active) the Cucamonga fault, Verdugo fault and the San Fernando segment of the Sierra Madre fault zone are class 1 range fronts, and the central part of the fault zone is a class 2 range front. Aerial photo analysis and field mapping from this study and those of Crook et al. (1987) show active fan deposition adjacent to class 1 range fronts, and fan head incision with active deposition down fan, away from the range along the class 2 range front. This further supports greater tectonic activity along the class 1 range fronts to the east and west. In summary, the vertical separation rate (uplift rate) decreases from about 3 mm/yr along the Cucamonga fault to around 1 mm/yr or less for the central Sierra Madre fault zone and San Fernando segment. These rates are far less than required to account for the estimated 6-8 mm/yr of shortening across the northern Los Angeles region and require other structures to account for the balance of the deformation.

At the western terminus of the class 1 range front along the Cucamonga segment, the left-lateral San Jose and Walnut Creek faults strike west-southwest away from the thrust system. In the central part of the class 2 range front, the left-lateral Raymond fault splays from the Sierra Madre fault zone, striking west-southwest. We here infer that these west-southwest striking faults distribute strain away from the Sierra Madre fault zone, in part resulting in decreasing slip along the central portion of the thrust system.

The west-southwest striking left-lateral faults are conjugate to the west-northwest striking Whittier-Elsinore fault zone, which collectively contributes 5 mm/yr of strain into the greater Los Angeles region. Together with the Santa Monica fault and possibly the Verdugo fault, which may have a significant lateral component as well, these faults comprise a conjugate system that accommodate north-south shortening by pure shear. Long term shortening has resulted in squeezing of the Santa Monica Mountains westward (Tsutsumi et al., 1995) at 3 mm/yr, as indicated by GPS data (Hudnut, personal comm.), the consequent escape of crystalline rock associated with the Perris block to the southeast of the San Jose and Walnut Creek faults as well as the block between the Raymond and Walnut Creek faults.

We believe that this conjugate system of strike-slip faults, with variable oblique components, accommodates half or more of the observed shortening. Consequently, the surface and blind thrusts have lower slip rates, and therefore are less of a seismic risk than presented in most recent models. This inference is directly supported by our recent work along the Sierra Madre fault zone, which is apparently accommodating no more than about 1.0-4.0 mm/yr shortening along its entire length, and suggests that more work is warranted along the Verdugo (proposed by Dolan and Rockwell to NEHRP) as well as the Raymond, Walnut Creek and San Jose faults.

Dogtails Versus Rainbows: Synthetic Earthquake Rupture Models as an Aid in Interpreting Geological Data

Steven N. Ward
University of California, Santa Cruz

Geologists have been collecting, for decades, information from historical and paleoearthquakes that could contribute to the formulation of a "big picture" of the earthquake engine. Observations of large earthquake ruptures, unfortunately, are always going to be spotty in space and time and I believe that the extent to which such information succeeds in contributing to a grander view of earthquakes is going to be borne not only by the quantity and quality of data collected, but also by the means by which it is interpreted. This paper addresses the need to more fully understand geological data through carefully tailored computer simulations of fault system ruptures. Dogtails and rainbows are two types of fault rupture terminations that can be recognized in the field and can be interpreted through these models. Rainbows are concave down ruptures that indicate complete stress drop and characteristic slip. Rainbow terminations usually coincide with fault ends or strong segment boundaries. Dogtails are concave up ruptures that indicate incomplete stress drop or stress increase and non-characteristic slip. Dogtail terminations can happen anywhere along a fault or fault segment. The surface slip pattern of the 1979 Imperial Valley earthquake show dogtail and rainbow terminations to the north and south respectively. The rainbow confirms the presence of a strong fault segment boundary six km north of the international border that had been suggested by Sieh (1996). The dogtail implies that the displacement observed in the 1979 quake is not characteristic. By combining information from the 1940 and 1979 surface slip patterns, paleoseismic data, and seismologically determined stress drop estimates, a quantitative Imperial fault model was developed with northern, central, and southern segments possessing 50, 110 and 50 bar strength and 28 1/2, 13 and 22 1/2 km length respectively. Both the 1940 and 1979 events showed 1-meter amplitude dogtailed ruptures of the northern segment; however, characteristic slip of the segment is more likely to be about 3 meters. To illustrate the full spectrum of potential rupture modes, models were run forward in time to generate 2000 year rupture "encyclopedia". Although the segmentation and strength of the Imperial fault are well constrained, modest changes in two friction law parameters produce several plausible histories. Further discrimination awaits analysis of the extensive paleoseismic record that geologists believe exists in the shore deposits of the intermittent lakes of the Salton Trough.

Compression Directions in Southern California (from Santa Barbara to Los Angeles Basin) Obtained From Borehole Breakouts

Melita Wilde and **Joann Stock**
California Institute of Technology

Borehole elongation in 66 drill holes was used to infer breakout orientation and directions of maximum horizontal principal stress S_H for six areas west of the San Andreas fault in southern California: Santa Barbara, Ojai, Central Ventura Basin, East Ventura Basin, West Los Angeles Basin, and East Los Angeles Basin. Breakouts were determined from analysis of oriented 4-arm caliper data. In most cases the data permit either a thrust faulting ($S_v < S_h < S_H$) or strike-slip faulting ($S_h < S_v < S_H$) stress regime with NE to NW directions of S_H. The variations in S_H directions suggest strong heterogeneity in the stress field at shallow depths, similar to that present in the Cajon Pass borehole [Shamir and Zoback, 1992]. For example, the S_H direction inferred from elongation of the SFSU374 and SFSU494 drill holes, near the Whittier fault, is NE, whereas nearby holes along the Whittier Fault and E of this area show an SH direction of NW to NNW. These variations in compression direction appear to be real, because they are from sections of nearly vertical drill hole (hole deviation < 5 deg). Such variations may be most prominent at fairly shallow depths (<2 km).

Anomalous NW directions of maximum horizontal compression were also found in nearly-vertical drill holes in the eastern San Fernando Valley. These may be related to the nearby lateral ramp in the frontal fault system of the San Gabriel Mountains (Kerkela and Stock, GRL, in press).

THE SURFACE GEOMETRY AND KINEMATICS OF THE SAN ANDREAS FAULT SYSTEM IN THE VICINITY OF SAN GORGONIO PASS

Douglas Yule and **Kerry Sieh**
California Institute of Technology

The historically dormant southern section of the San Andreas fault (SAF) is generally regarded as the most likely source of the next great earthquake in southern California. However, the future behavior of the fault in southern California is difficult to constrain, in large part due to the complexity of the fault system in the vicinity of San Gorgonio Pass. One possibility is that a complex tangle of faults effectively act as a barrier, or "knot", and prevent large earthquakes from propagating through the Pass. Alternatively, very large earthquakes are likely to occur if San Gorgonio Pass contains a continuous structure, or a set of connected structures, that can carry the rupture through the region.

The preliminary findings of this study lend support to the latter scenario. Specifically, a set of recently active, en echelon and transfer structures connect the eastern end of the South Branch of the SAF to the western end of the Coachella Valley segment of the Banning fault. This through going system consists of northwest striking, dextral slip faults; south dipping, normal-dextral slip faults; east and west dipping normal faults; north dipping thrusts; and south dipping landslide head scarps. Kinematically, the thrust faults, the east-west dipping normal faults, and the dextral slip faults are interpreted as the respective shortening, extensional, and strike-slip components of an incipient dextral shear zone. The cumulative displacement across these structures is constrained by a dextral offset of approximately 1-2 km at both Millard and Potrero Canyons. The head scarps and south dipping normal faults are superimposed on the right-lateral shear components and are interpreted to have formed in the axial planar region of a fault bend fold. These extensional features are created by the change in orientation of the fault from subvertical at depth to an ~25-45 degree northward dipping structure near the surface. Thus, the surface geometry of the SAF at San Gorgonio Pass, though highly complex, is nonetheless through going and is potentially capable of generating a very large earthquake.

Conditions under Which Velocity-Weakening Friction Allows a Self-Healing Versus Crack-Like Mode of Rupture

Gutuan Zheng and **James R. Rice**
Harvard University

We have found a self-healing pulse mode of rupture in elastodynamic modeling of velocity weakening faults between elastic half-spaces under the following conditions: (1) Under-stressing, as further explained below; (2) Aging; friction laws must allow restrengthening in stationary contact (Perrin et al., 1995). Further we found a single parameter T that can be used to classify the rupture patterns by representing the velocity weakening at a characteristic velocity; T reflects not only weakening in the fault constitutive law, but also effects of the loading conditions.

When slip rate $V > 0$ the shear stress τ on the fault plane satisfies both $\tau = \tau_{str}$ and $\tau = \tau_o + \phi - (\mu/2c)V$ where $\tau_{str} = \tau_{str}(V, \text{state})$ is the fault strength, τ_o is the remote loading level, ϕ is the elastodynamic functional representing the effects of spatially non-uniform slip history, μ is the shear modulus and c the shear wave speed. At steady state $\tau_{str} = \tau_{ss}(V)$. "Under-stressing" means τ_o is so low that $\tau_o - (\mu/2c)V < \tau_{ss}(V)$ for all V. The maximum value of such τ_{ss} is called τ_{pulse}. We prove that an indefinitely expanding crack-like rupture solution does not exist if $\tau_o < \tau_{pulse}$, implying only the pulse, either growing indefinitely or arresting, can then be the solution.

Defining V_{dyna} as the (larger) velocity solution, if any such exists, at which $\tau_{ss}(V) = \tau_o - (\mu/2c)V$, $T = [-d\tau_{ss}(V)/dV]/(\mu/2c)$ at $V = V_{dyna}$. $T = 1$ when $\tau_o = \tau_{pulse}$ and T is not defined (no intersection) for smaller τ_o. We show rupture simulations for two velocity weakening laws for a fault initially at rest, then suddenly subjected to the uniform stressing τ_o plus a perturbation to over-stress the fault in a small region to nucleate the ruptures. Those with T near 1 or not defined give pulse solutions. Those with T near 0 (e.g., $T < 0.2$) show crack-like solutions. T near 0.5 is associated with transitional behavior.

A Quality Assessment of First Motion Focal Mechanisms

Hua-Wei Zhou and **Tom Bjorklund**
University of Houston

First motion focal mechanisms are widely used in studies of active tectonics. Takeoff angles for focal mechanisms are normally calculated from 1-D seismic velocity models and, for some refracted ray paths, are insensitive to epicentral distances. In these cases, first motion data appear as circular girdles on the focal sphere. In contrast, takeoff angles calculated from 3-D velocity models generally do not exhibit patterns of circular girdles. Additionally, in nearly all cases multiple focal mechanism solutions fit first motion data equally well. A measurement of the spread of the equally good solutions together with a fitting correlation may be one way to quantify focal mechanism quality. Studies to evaluate the effect of these ideas on focal mechanism interpretations of recent earthquakes in the Los Angeles Basin are in progress.