



Southern California Earthquake Center

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Jill Andrews, Director

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Southern California Earthquake Center

1995 Annual Meeting

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September 17-19, 1995

Ojai Valley Inn Ojai, California

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1995 SCEC ANNUAL MEETING AGENDA

Sunday, September 17

- 10:00 a.m. Field Trip led by Tom Rockwell and Gary Huftile
- 7:00 p.m. Poster Session and Icebreaker
- 9:00 p.m. SCIGN Meeting
- 9:30 p.m. Advisory Council Meeting

Monday, September 18

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

Welcome and Introduction	Heney (10)
Statement from NSF	Whitcomb (10)
Statement from USGS	Sims (10)
Phase III Report	Norm Abrahamson (30)
Status of GPS Initiative	Duncan Agnew (15)
Results of LARSE	Robert Clayton (15)
New Seismic Network Initiative	Egill Hauksson (15)

Break @ 9:45 a.m.

Status of Northridge Investigations	Jim Mori (15)
Research Utilization Council	Jill Andrews (15)
Summary Reports from Group Leaders	Kei Aki, Steve Day, Kerry Sieh, Rob Clayton, Duncan Agnew, Egill Hauksson, Leon Knopoff (5 each)

Lunch @ 11:45 a.m.

Session II. Plenary Session

1:00 p.m. Invited Talks (30 minutes each)

Jim Rice and Yehuda Ben-Zion: Rupture Dynamics, Slip Patterns and Event Populations in Earthquake Fault Models

Lynn Sykes and Jishu Deng: Evolution of the Stress Field in Southern California During the Past 200 Years and Implications for Long-Term Earthquake Prediction

Ruth Harris, Ross Stein, and Robert Simpson: Earthquake Stress Triggering and Relaxation Shadows - An Explanation for the Pattern of Southern California Earthquakes from 1858-1995

Session III: Working Group Meetings

2:30 to 4:15 p.m.	Group A:	Aki
4:15 to 6:00 p.m.	Groups B & H: Group C: Group D:	Day/Martin Sieh Clayton
Dinner at 6:00 p.m.		
7:15 to 9:00 p.m.	Group E: Group F: Group G:	Agnew Hauksson Knopoff
9:00 to 10:45 p.m.	Education and Knowledge Transfer:	Abdouch/Andrews

Tuesday, September 19

8:00 a.m. Session IV: Reports on Future Plans from Group Leaders

Engineering Applications Group Report	Martin
Group G (Earthquake Physics)	Knopoff
Group F (Regional Seismicity)	Hauksson
Group E (Crustal Deformation)	Agnew
Group D (Subsurface Imaging)	Clayton
Group C (Earthquake Geology)	Sieh
Group B (Strong Motion)	Day
Group A (Master Model)	Aki
Education and Knowledge Transfer	Abdouch/Andrews
Meeting Summary and Discussion	Heney

End of SCEC Meeting

Lunch @ noon for SCEC Advisory Council and Steering Committee

Advisory Council meets in Executive Session after lunch.

1995-96 SCEC ANNUAL MEETING AND PROPOSAL SCHEDULE

ANNUAL MEETING SEPTEMBER 17-19, 1995	REVIEW OF 1995 SCEC ACTIVITIES GROUP MEETINGS - REVIEW AND PLANNING FOR 1996 CONSENSUS REPORTS ON 1996 PLANS PRESENTED BY GROUP LEADERS MEETING OF ADVISORY COUNCIL
SEPTEMBER 29, 1995	GROUP LEADERS PROVIDE WRITTEN SUMMARIES OF GROUP PLANS TO AKI
EARLY OCTOBER, 1995	CALL FOR PROPOSALS FOR 1996
NOVEMBER 17, 1995	1995 PROGRESS REPORTS AND 1996 PROPOSALS DUE AT SCEC
LATE NOVEMBER, 1995	PROPOSAL PACKETS SENT TO GROUP LEADERS FOR REVIEW
LATE DECEMBER 20, 1995	GROUP LEADER RECOMMENDATIONS TO AKI AKI REVIEWS OVERALL PROGRAM
JANUARY 12, 1996	GROUP LEADERS PROVIDE SUMMARIES FOR ANNUAL REPORTS TO NSF AND USGS
MID-JANUARY, 1996	AKI RECOMMENDATIONS SENT TO SCEC STEERING COMMITTEE
JANUARY 26, 1996	STEERING COMMITTEE MEETS TO REVIEW AKI RECOMMENDATIONS
EARLY FEBRUARY, 1996	SCEC BOARD VOTES ON 1996 PLAN NSF/USGS NOTIFIED OF FUNDING PLAN SCEC ANNUAL REPORT DUE TO NSF/USGS
LATE FEBRUARY, 1996	1996 AWARDS ANNOUNCED
SPRING, 1996	SUBCONTRACTS ISSUED

1995 SCEC ANNUAL MEETING PARTICIPANTS

Mark Abinante	UC-Los Angeles
Curt Abdouch	USC
Abrahamson, Norm	Consultant
Duncan Agnew	UC-San Diego
Kei Aki	USC
John Anderson	Nevada-Reno
Jill Andrews	USC
Ralph Archuleta	UC-Santa Barbara
Tanya Atwater	UC-Santa Barbara
Yehuda Ben-Zion	Harvard
Jacobo Bielak	Carnegie-Mellon
Ann Blythe	USC
Yehuda Bock	UC-San Diego
David Bowman	USC
Andrew Byers	SCEC Summer Intern/UCSB
Windy Brimer-Elliott	SCEC Summer Intern/UCSB
Sergio Chavez-Perez	Nevada-Reno
James Chin	USC
Rob Clayton	Caltech
Cheryl Contopulos	Caltech
Anne Cooper	Triton Research
Allin Cornell	Stanford
Debbie Dager	Caltech
Jim Davis	CDMG
Paul Davis	UC-Los Angeles
Thom Davis	Davis & Namson
Steve Day	San Diego State
Jim Dieterich	USGS-Menlo Park
Jim Dolan	USC
Danan Dong	JPL
Andrea Donnellan	JPL
Geoff Ely	UC-Santa Barbara
Ned Field	USC/Lamont
Mike Forrest	USC
Tom Fumal	USGS-Menlo Park
Shang-xing Gao	UC-Los Angeles
Eldon Gath	Leighton & Associates
Lisa Grant	Chapman College
Robert Graves	Woodward-Clyde
Katrin Hafner	Caltech
Bob Hamilton	USGS-Reston

Jeanne Hardebeck	Caltech
Ruth Harris	USGS-Menlo Park
Egill Hauksson	Caltech
Liz Hearn	Oregon
Tom Heaton	Caltech
Don Helmberger	Caltech
Tom Henyey	USC
Alan Hoffman	San Marcos High School
Bill Holt	SUNY-Stony Brook
Scott Hornafius	UC-Santa Barbara
Ken Hudnut	USGS-Pasadena
Gary Huftile	Oregon State
Gene Humphreys	Oregon
Ken Hurst	JPL
Dave Jackson	UC-Los Angeles
Anshu Jin	USC
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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
Bob King	MIT
Leon Knopoff	UC-Los Angeles
Monica Kohler	UC-Los Angeles
Matthew Lee	UC-Los Angeles
Mark Legg	ACTA
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Yong-gang Li	USC
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John Louie	Nevada-Reno
Bruce Luyendyk	UC-Santa Barbara
Ian MacGregor	NSF
Harold Magistrale	San Diego State
Mehrdad Mahdyiar	Vortex Rock Consultants
Aaron Martin	UC-Santa Barbara
Geoff Martin	USC
Shirley Mattingly	FEMA
Sally McGill	Cal State-San Bernardino
John McRaney	USC

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Jim Mori
Karl Mueller
Lalliana Mualchin
Xian-xi Ni
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Robert Nigbor
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Kim Olsen
Randy Palmer
Bill Petak
Mark Petersen
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Will Prescott
Jose Pujol
Mike Reichle
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Tom Rockwell
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Charlie Rubin
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Li-Hong Sheng
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Bishop Garcia Diego HS
KFWB
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UC-Berkeley
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Woodward-Clyde
USC
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Caltech
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UC-Los Angeles
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Leon Teng
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Alla Tumarkina
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1995 SCEC FIELD TRIP PARTICIPANTS

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Jill Andrews	USC
Ralph Archuleta	UC-Santa Barbara
Tanya Atwater	UC-Santa Barbara
Yehuda Ben-Zion	Harvard
Jacobo Bielak	Carnegie-Mellon
Ann Blythe	USC
David Bowman	USC
Windy Brimer-Elliott	UCSB
Rob Clayton	Caltech
Cheryl Contopulos	Caltech
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Andrea Donnellan	JPL
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Katrin Hafner	Caltech
Liz Hearn	Oregon
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Alan Hoffman	San Marcos High School
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SCEC ORGANIZATION - 1995

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Director for Knowledge Transfer: Jill H. Andrews
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Board of Directors

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Ex-officio: Thomas Henyey
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Research Group Leaders

A: Master Model:	Keiiti Aki University of Southern California
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:	Duncan Agnew University of California, San Diego
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

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Arvid Johnson

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Thomas Rockwell

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Paul Segall

Jian Lin

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Lindvall, Richter, Benuska, Associates, Inc.
Pasadena, California

S-Cubed, Inc.
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Vortex Rock Consultants
Diamond Bar, California

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Institut de Physique du Globe
Strasbourg, France

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Mark Legg

Thom Davis
Jay Namson

Eldon Gath

Scott Lindvall

Keith McLaughlin

Mehrdad Mahdyiar

Chandan Saikia

Juan Madrid

Geoffrey King

Southern California Earthquake Center

1994-1995 Post-doctoral Fellows and Visitors Program

<u>Visitor</u>	<u>Institution (Host)</u>	<u>Research Project</u>
Y. John Chen (Oregon State)	UCSD (Minster)	Finite Element Modeling of Three-Dimensional Interaction/Coupling between Blind Thrust and Strike-Slip Faults in the Los Angeles Basin
Edward H. Field (Post-doctoral Fellow) Ph.D., Columbia	USC (Aki)	Toward a Better Understanding of Earthquake Site Response in Terms of Hazard Assessment
Stefan Nielson (Post-doctoral Fellow) Ph.D., Paris	UCLA (Knopoff)	Simulation of Dynamic Rupture
Kim B. Olsen (Post-doctoral Fellow) Ph.D., Utah	UCSB (Archuleta)	M8+ Earthquake in Southern California?
Guang Yu (Post-doctoral Fellow) Ph.D., Nevada-Reno	San Diego State (Day)	Prediction of Strong Ground Motion
J. Douglas Yule (Post-doctoral Fellow) Ph.D., Caltech	Caltech (Sieh)	Neotectonic and Paleoseismic Investigation of the San Andreas Fault System in the Vicinity of San Geronio Pass
Jiakang Xie (St. Louis University)	USC (Aki)	Fault Zone Structure Study by Slowness Power Spectrum Analysis of the 1992 Joshua Tree Aftershock Data

1995 SCEC Funding

NSF Regular Program	\$2.920M
USGS Regular Program	\$1.200M
FEMA Regular Program	\$0.125M
FEMA Supplement	<u>\$0.085M</u>
Total Funds Available:	\$4.330M

Funds Budgeted:

Infrastructure	\$1.760M
Science	\$2.040M
Education and Outreach	<u>\$0.530M</u>
Total Program	\$4.330M

Note: Proposal to Caltrans for 3-year renewal @ \$0.750M per year pending.

SCEC Budgets, 1991-1995

	1991	1992	1993	1994	1995
Management	240	225	223	240	260
Workshops/Meetings	45	90	60	100	98
Visitors	290	150	110	175	290
Data Center	297	200	181	225	225
Strong Motion Data Base	0	30	35	60	50
Broad Band Center	282	200	202	170	125
GPS Data Analysis	475	410	310	355	385
GIS	80	70	105	85	92
Earthquake Geology GIS	0	0	95	90	90
Education and Outreach	30	100	90	300	320
Pinon Flat	0	20	20	50	95
TERRASCOPE	0	60	60	55	50
Subtotal	1,739	1,555	1,490	1,905	2,080
Post Earthquake Studies		289		715	
			Science		
A/Master Model	150	223	299	432	475
B/Ground Motion Prediction	200	167	163	240	271
C/Earthquake Geology	200	399	281	465	467
D/Tectonics and Subsurface Imaging	275	170	82	506	261
E/Crustal Deformation	160	117	136	141	237
F/Seismicity and Source Processes	145	150	145	205	157
G/Physics of Earthquake Sources	200	154	95	151	172
Subtotal	1,330	1,380	1,201	2,140	2,040
Total Obligated	3,069	2,935	2,980	4,760	4,120
Total Funding	3,250	2,754	2,980	4,760	4,120

•SCEC 1991 Discipline Task Matrix for Science

	Group A	B	C	D	E	F	G	Sub-Total
Task 1	188	20	70	40	70			388
Task 2	16	103	80	70		35		304
Task 3	15	76	44	165	75	50	57	482
Task 4	11				10		143	174
Task 5						60		60
Sub-Total	230	199	194	275	165	145	200	1,408

•SCEC 1992 Discipline Task Matrix for Science

	Group A	B	C	D	E	F	G	Sub-Total
Task 1	151		45		75			271
Task 2	60	40	282	80		40		502
Task 3	40	109	8	90	38	40	52	377
Task 4	23						72	95
Task 5						70		70
Sub-Total	274	149	335	170	113	150	124	1,315

•SCEC 1993 Discipline Task Matrix for Science

	Group A	B	C	D	E	F	G	Sub-Total
Task 1	80		26		27			133
Task 2	65	142	118	52	69			446
Task 3	40	21	137	30	40	95	61	424
Task 4	114						34	148
Task 5						50		50
Sub-Total	299	163	281	82	136	145	95	1,201

•SCEC 1994 Discipline Task Matrix for Science and Northridge Response

	Group A	B	C	D	E	F	G	Sub-Total
Task 1	158	14	134	28	28			362
Task 2	43	215	108	24	45		32	467
Task 3	173	11	223	447	54	138	83	1,129
Task 4	55					10	36	101
Task 5	3			7	14	57		81
Task 6	35	80	22		132	446		715
Sub-Total	467	320	487	506	273	651	151	2,855

•SCEC 1995 Discipline Task Matrix for Science

	Group A	B	C	D	E	F	G	Sub-Total
Task 1	255	87	29					371
Task 2		184	190					374
Task 3	171		248	261	222	97	108	1,107
Task 4	49				15		64	128
Task 5						60		60
Task 6								
Sub-Total	475	271	467	261	237	157	172	2,040

1995 SCEC Program

Principal Investigator	Title	Working Group
Curt Abdouch/Jill Andrews	1995 SCEC Education and Outreach Program	E/O
Rachel Abercrombie	Anomalous Scaling of Radiated Seismic Energy	F
Norm Abrahamson	Coordination of Seismic Hazard and Ground Motion Modeling Studies	A, B
Duncan Agnew/Frank Wyatt/Hadley Johnson	Understanding and Reducing Monument-Related Noise in Geodetic Measurements	E
Kei Aki/Eric Lehmer	1995 SCEC GIS Operations at USC/UCR	I
Kei Aki	1995 SCEC Meetings and Workshops	I
Kei Aki	1995 Post-Doctoral and Visitor Program	I
Kei Aki/Tom Henyey	1995 SCEC Management Operations	I
Kei Aki/James Chin	The Evaluation of Attenuation Relation for Probabilistic Seismic Hazard Analysis in Southern California	A
Kei Aki/James Chin	Updating GIS-Based Maps of Coda Amplification Factor in Southern California	A
Kei Aki/Anshu Jin	Study on the Source Parameters of Northridge Aftershocks Using Spectral Ratio Method to Telescope Data	F
John Anderson/Raj Siddharthan/Yuehua Zeng	Seismological Perspective on Theoretical Non-Linear Effects on Strong Ground Motion in Saturated Media	B
John Anderson/Yuehua Zeng/Feng Su	High Frequency Ground Motion by Regression and Simulation	B
Ralph Archuleta/Robert Pizzi	Seismology Curriculum Using Cube for Santa Barbara County Schools	E/O
Ralph Archuleta	Portable Broadband Instrumentation	I
Ralph Archuleta/Alexei Tumarkin	SCEC Strong-Motion Database SMDB and Empirical Green's Functions Library EGFL	I
Ralph Archuleta/Alexei Tumarkin	Empirical Time-Series Simulation of Phase-III Scenario Earthquakes	B
Yehuda Ben-Zion/Jim Rice	Seismicity Patterns Along Complex Fault Systems and Basis for Evaluating Seismic Risk and Precursors	G, A
Yehuda Bock	Infrastructure Support for Southern California Integrated GPS Network (PGGA & DGGA)	I
Rob Clayton	SCEC Data Center Operations	I

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Rob Clayton	LARSE Workshops	I
Rob Clayton	Analysis of LARSE Line 1	D
Allin Cornell	Southern California Probabilistic Seismic Hazard Analysis	A
Paul Davis	Site Effects from NEAR94 Data	B
Paul Davis	Integration and Analysis of LARSE ACTIVE and PASSIVE Data	D
Thom Davis/Jay Namson	Mapping and Delineation of the Elysian Park Thrust, Los Angeles Basin	C
Steve Day/Keith McLaughlin	Three-Dimensional Simulation of Long Period Ground Motion in L.A. Basin	B
Steve Day/Ruth Harris	3D Dynamic Modelling of Earthquakes Encountering Fault Bends and Non-Parallel Fault Strands	G
Jim Dolan	Paleoseismology, Neotectonics, and Seismic Hazards of the Hollywood-Santa Monica-Malibu Coast Fault System	C
Danan Dong	Combining Geodetic Data to Estimate Interseismic Deformation Field in Southern California and Fault Dislocation Parameters	E
Andrea Donnellan	Geological and Design Issues of Continuous GPS Network	I
Eldon Gath	Bringing Earthquake Risk to the California State Legislature: An Earthquake Hazards Seminar that Involves the Decision and Policy Makers of the State of California	E/O
Lisa Grant/John Waggoner	Continued Paleoseismic Studies of the Newport-Inglewood Fault zone, Southern California	C
Brad Hager	Continuum Mechanics Models of Blind Thrusts in the L.A. Basin	C, A
Egill Hauksson	Precise Location and Mechanisms of Aftershocks and Stress State of the 1994 M6.7 Northridge Earthquake	F
Egill Hauksson	Interactive Earthquake Information Display	E/O
Egill Hauksson/Jennifer Haase/Rob Clayton	L.A. Basin Tomography With The LARSE and Northridge Datasets	D,
Egill Hauksson/Hiroo Kanamori	Towards, Real Time, Routine Broadband Seismology	F
Don HelMBERger	Rapid Source Retrieval	F
Tom Henyey/David Okaya	Development of a Subsurface Geophysical Data Base for Southern California	A
Tom Herring/Robert King	Towards an Improved Error Model for GPS Observations	E
Scott Hornafuis/Bruce Luyendyk	Seismic Mapping of the North Channel Fault Near Santa Barbara, CA	C, D

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Eugene Humphreys	Modeling of the Southern California Deformation Towards a Physical Master Model	D
Dave Jackson/Yan Kagan/Z. Shen	Seismic Hazard Estimation	A
Dave Jackson/Duncan Agnew	Geodesy Infrastructure	I
Arvid Johnson	Kinematic Analysis of Coseismic Surface Deformation Along Part of Emerson Fault Zone, Landers, California, 1992 Earthquakes	E
Hadley Johnson/John Suppe/Duncan Agnew	Development of a Geologically and Geophysically Reasonable Thrust Fault Model for the Los Angeles Basin	E, C
Yan Kagan/Dave Jackson/Z. Shen	Stress Modeling	A
Marc Kemerling/Craig Nicholson	Continuation of SCEC Study of Blind Thrust Faults	C
Hiroo Kanamori/Egill Hauksson	Enhancement of Telescope	I
Ed Keller/Jim Dolan	Earthquake Hazard: Ventura-Santa Barbara	C
Robert King/Tom Herring	Support for GPS Analysis	E
Robert King	Geodetic Constraints on Interseismic, Coseismic, and Postseismic Deformation in Southern California	E
Leon Knopoff	Investigation of Low-Friction Sliding	G
Leon Knopoff	Simulations of Dynamic Inplane Rupture Source Effects	G
Leon Knopoff	Model of the Southern California Fault Network	G
Yong-Gang Li/Kei Aki	Study of Fault Segmentation Near Anza, California, Using Fault Zone Guided Waves	D
Jian Lin/Geoff King	Investigation of Coseismic and Postseismic Coulomb-Stress Changes Caused by Blind-Thrust Earthquakes in the Los Angeles Basin	A, E
Scott Lindvall	Paleoseismology of the Western Sierra Madre Fault Zone	C
Greg Lyzenga/Andrea Donnellan	Expected Interseismic Surface Deformation From Blind Thrust Structures	E
Mehrdad Mahdyiar	Probabilistic Ground Motion Analysis of Southern California and Development of an Interactive Software and Database for Such Analysis	A
Geoff Martin/Mladen Vucetic	Enhancement of the SCEC Geotechnical Data Base to Accommodate Nonlinear Site-Response Analyses	B
Sally McGill	Paleoseismic Studies of Active Faults in the San Bernardino Area	C
Sally McGill/Lisa Grant	Workshop on Preparing a Digital Fault Map and Database for Southern California	I
Bernard Minster	Investigations of Intermediate-Term Earthquake Prediction Algorithms	A

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Craig Nicholson	Seismicity Studies of the Santa Barbara-Ventura Area	F
David Okaya/Tom Henyey	Los Angeles Region Seismic Experiment: Direct Imaging of Crustal Structure Under the L.A. Basin as Derived from Wide Angle Reflection Imaging of the LARSE Onshore-Offshore Transects	D
David Okaya/Tom Henyey	Structural Geometries of the Transverse Ranges Fold and Thrust System: Application of Industry Seismic Reflection Profiles	D
Steve Park	Phase III - Site Amplification Map Creation	A
Steve Park/Eric Lehmer	GIS Center Activities	I
Ken Potter	Hands-on Earthquake Learning Kits to Educate and Motivate	E/O
James Rice/Yehuda Ben-Zion	Elastodynamics of Rupture Propagation and Arrest in Relation to Generating and Sustaining Complexity of Seismic Response	G
Tom Rockwell	Dating of Holocene Earthquakes in the Landers Area	C
Tom Rockwell	Paleoseismology of the Compton Los Alamitos Structure	C
Chandon Saikia	Time Histories at Los Angeles Basin Sites From a SCEC San Andreas Scenario Event Generated by Using 1D and 2D Large Scale (Deep Basin) and Small Scale (Micro)	B
Charles Sammis	Spatial and Temporal Patterns of Precursory Seismicity	G
Nano Seeber/John Armbruster	Fault Kinematics, Stress and Stress Changes From Focal Mechanisms in Southern	A, F
Paul Segall	Error Sources in Geodetic Time Series	E
Z. Shen/Dave Jackson	Crustal Deformation Modeling	E
Kerry Sieh	Structural Studies of the Landers Earthquake	C
Kerry Sieh	Do Ruptures of the San Andreas Fault Typically Begin, End or Hang Up Near San Gorgonio Pass?	C
Kerry Sieh/Anne Lijje	Computational Support for Paleoseismic and Neotectonic Studies	I
Joann Stock	Compilation of New and Existing Stress Observations for Southern California	D
John Suppe	ARC/INFO Based Mapping and Structural Analysis of Active Blind Thrusts in Southern California	A, C
John Suppe/Karl Mueller	Paleoseismic Studies of Active Blind Thrusts in the Los Angeles Basin and Western Transverse Ranges, Southern California	C

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Lynn Sykes/Roger Buck/Bill Menke	Development of a Physical Model of Stresses in Southern California and Changes in Rates of Historic Seismicity as an Intermediate-Term Earthquake Precursor	A
Mary Templeton	Refining High-Resolution Seismic Reflection Imaging as a Tool for Paleoseismic Studies: Faulted Structure and Features in the Upper 50 feet	D
Alexei Tumarkin/Jamie Steidl	Strong Motion Site Amplification Factors in the Los Angeles Metropolitan Region	B
Steve Ward	A Multidisciplinary Approach to Earthquake Hazard in Southern California	A
Steve Ward	Synthetic Seismicity Models of Southern California: A Step Toward the Master Physical Model	A
Steve Wesnousky	Continued Development of Groundwork for Construction of Seismic Hazard Maps	A
Frank Wyatt/Duncan Agnew	Pinon Flat Observatory -- Continuous Monitoring of Crustal Deformation	I
Bob Yeats/Gary Huftile	Interaction Between Blind Thrusting and Strike Slip Between the Whittier Fault and the Los Angeles Fold and Thrust Belt	C
Bob Yeats/Jon Kimerling	Quaternary and Tertiary Structures of the Northern Los Angeles Basin: Creating a Digital Three-dimensional Spatial Database	A
Yuehua Zeng/John Anderson	2 Simulations of Ground Motion in the Los Angeles Basin: Simplified Approaches	B

**Reports from Directors of the
Southern California Earthquake
Center**

Why Fundamental Earthquake Science?

The Answer is in What is Happening at SCEC

Keiiti Aki

The population in the world's earthquake belts is increasing at a rapid rate, and with few resources at people's disposal, they are building dwellings too feeble to withstand even modest shaking. In Mexico City, Istanbul, Cairo, Mindanao, Jakarta, and Athens, the population at risk mounts sharply and irrevocably each year. Elsewhere in the world, cities such as Tokyo, Taipei, San Francisco, Los Angeles, Salt Lake City, Vancouver, Naples, and Nice, rely on a complex and delicate infrastructure that we now realize is highly vulnerable to strong earthquakes. The destruction of these cities in a great earthquake will echo throughout the world financial markets in ways not yet imagined. How can we mitigate this seemingly inevitable human pain and suffering? How can we warn people, dislodge the population, or redesign cities?

Almost everything we now know about earthquakes and how to deal with them has been learned from the laborious work of generations of scientists who were fascinated by the awesome power of nature released in earthquakes, as well as intrigued by the possibility of predicting their occurrence by scientific methods. The most important information we have is the record of past earthquakes, culled from a global seismic network begun about the beginning of this century. The magnitude-frequency distribution, first extracted from the global data in the 1940's, is now one of the cornerstones of seismic hazard estimation around the globe. Fundamental data on the geometry and slip rates of faults come largely from geologic investigations, most carried out in the last decade. The theory of plate tectonics, now only thirty years old, revolutionized the earth sciences, and for the first time explained the origin of earthquake stresses. The concept of seismic moment, which measures the total slip in an earthquake, links earthquake rates to plate tectonic rates. This concept is also only thirty years old. The characteristic earthquake model, which relates the size of future earthquakes to the rupture length of past earthquakes, is barely ten years old. It has found widespread use in seismic hazard estimation but is only now being rigorously tested. Just in the last several years we have begun using the Global Positioning System (GPS) to measure strain accumulating within the crust and relating this strain to earthquake potential.

The time was ripe when the Southern California Earthquake Center (SCEC) was created to integrate and distill knowledge accumulated in these fundamental research areas such that it could be transmitted to the public in a form useful for earthquake hazard preparedness. At the same time, SCEC has been able to explore new frontiers of earthquake science to better understand earthquake hazard, risk, design, and loss. In fact, one of the things SCEC has done best is to permit the incubation of out-of-the-mainstream ideas. In most other organizations, ideas off the beaten path are stillborn or left for dead. SCEC, on the other hand, played a valuable role in nurturing new ideas as exemplified by developments leading to its Phase 1, 2 and 3 reports. Obviously, parenting ideas is riskier than adopting existing ones, but it is needed to advance earthquake science in a fundamental manner.

SCEC has also made a rare and conscious effort to promote communication among researchers, and between the producers and consumers of earthquake knowledge. SCEC realized that if our understanding is to progress, we cannot afford to compartmentalize research by discipline, or worse yet, by institution. It has built gates rather than walls; it

has been inclusive and nurturing, rather than arrogant. SCEC has urged researchers to share, rather than guard, what they know. And it has worked.

The Phase 1 and 2 reports, the distributed data centers, our newsletters and home page on the internet, the monthly topical workshops, the inroads with FEMA, NASA, Caltrans, the oil industry, educators, teachers, and students are emblems of the synergy of SCEC. These efforts are rooted in the advancement of fundamental science, and at the same time, reach out in many directions to promote awareness and understanding. Most important, they serve to foster an environment in which we must be students of what we fear, and we must learn if we are to cope.

More than six years ago, in May, 1989, a workshop was held at Lake Arrowhead, California attended by those concerned with seismic hazards in southern California. The workshop decided to create SCEC and seek funding from the Science and Technology Centers Program of NSF. Many fundamental problems needed to be solved for understanding earthquake hazards; they were identified in the workshop and were organized into the goal of the Center, namely, to develop a master model of seismic hazard in southern California. The proposal to NSF was successful, and SCEC began its activities in the beginning of 1991. During the past 4 1/2 years, SCEC has reached a consensus in adopting the following six tasks which by and large address the problems identified at the Lake Arrowhead meeting.

- Task 1: Construct maps of probabilistic seismic hazard of southern California.
- Task 2: Develop plausible earthquake scenarios emphasizing the Los Angeles basin.
- Task 3: Study fundamental relationships among fault structures, dynamics, and the earthquake recurrence process.
- Task 4: Develop and test intermediate-term earthquake prediction methodology.
- Task 5: Support the development of real-time earthquake information.
- Task 6: Provide response to future earthquakes.

In essence, the first three tasks represent a hierarchical approach toward the Center's goal to develop a master model of seismic hazard in southern California. Task 1 is at the highest hierarchical level in terms of application, and generates a knowledge base for public policy on seismic hazards for the whole of southern California.

Task 2 represents applied research focused to a smaller region for generating higher-quality, more detailed knowledge base. We were fortunate that our choice of the Los Angeles basin as the focus has been more than justified by the Northridge earthquake of 1994.

Task 3 represents multidisciplinary research of a more fundamental nature, which will be incorporated into future versions of the master model.

Task 4 has high stakes for society, and Task 5 has important public utility although it may not need the center mode of research.

The need for Task 6 is evident in view of the recent high rate of earthquake occurrence in southern California.

It is interesting to compare these current tasks with what was discussed at the Lake Arrowhead meeting more than six years ago. The scientific problems proposed as subjects of study for a future SCEC are summarized in the appendix which is based on a document prepared by W. Stuart who co-chaired a subgroup on scientific objectives and strategies at the meeting. In the summary, the subjects are grouped into 4 categories; (A) Regional

Master Models, (B) Earthquake Rupture Process, (C) Strong Ground Motion Prediction, and (D) Real Time Seismology.

We find that the center's Tasks 2 and 5 precisely correspond to the subject categories C and D, respectively, while A and B are well represented in Tasks 3 and 4. At the Lake Arrowhead meeting, however, the center's highest priority, Task 1, was not recognized as an important subject of study. Its importance was recognized through many workshops held after Lake Arrowhead, and was included explicitly in the proposal to NSF; i.e., "to integrate research findings from various disciplines in earthquake-related science to develop a prototype probabilistic seismic hazard model (Master Model) for southern California". During 5 year's work at SCEC, the probabilistic seismic hazard analysis (PSHA) has proved to be extremely useful not only for the integration but also for promoting cooperative multidisciplinary researches on seismic hazard. As exemplified in the Phase 2 Report, PSHA served as a framework for integrating information from various disciplines including geology, geodesy, seismology, and geotechnical engineering engaged in the assessment of seismic hazards in southern California. In fact, the Phase 2 Report, published in the Bulletin of the Seismological Society of America, has become SCEC's first generation Master Model. Although Task 1 is the highest priority at SCEC, it is not the most demanding in terms of funding. On the average, 17% of the total science budget was allotted to Task 1 over the last 5 years, while Tasks 3 and 4 which address fundamental research categories A and B (see Appendix) received roughly one-half the science budget.

The Phase 2 Report produced an unexpected outcome beyond the original purpose of transferring earth science information to the user community. It identified outstanding scientific issues from the finding that, on the basis of combined geologic, geodetic, and seismological data, annual rate of earthquakes in southern California with M greater than or equal to 7 is predicted to be twice the observed rate since 1850. This difference can be attributed to:

- the maximum magnitudes assigned on the basis of the length of fault segments may be underestimated,
- part of the apparent geodetic strain may be released aseismically, and/or
- the seismicity of southern California in the past 150 years may have been anomalously lower than the long-term rate indicated by geologic and geodetic data.

These issues were mentioned in categories A and B of research subjects discussed at Lake Arrowhead, but now have been given greater emphasis. Thus the outcome of applied research (in this case the preparation of the Phase 2 report as part of SCEC's knowledge transfer process) can set priorities for future fundamental research. This is a newly recognized outcome of SCEC's center mode of research.

SCEC has also encouraged interdisciplinary interaction among fundamental research activities. For example, seismologists and geotechnical engineers have started working together on the question of non-linear soil response. The discovery of fault zone trapped modes for the Landers fault segments has provided an effective tool for seismologists to compare fault zone structure at depth with surface observations by geologists as well as the kinematics and dynamics of fault rupture studied by seismologists and geodesists. SCEC has helped recognize that fundamental research by one discipline is needed by another, and vice versa. Mutual needs of different disciplines in multidisciplinary work naturally increase the constituencies supporting each discipline.

Despite SCEC's efforts with its streamlined tasks from fundamental to applied research, we are still far from forecasting, let alone predicting, earthquakes. Earthquake forecasting involves understanding a variety of complex physical processes including tectonic loading and relaxation, the geometry, rheology, and fluid environment of faults, rupture nucleation and the dynamics of rupture propagation and stopping. A somewhat simpler problem is how an earthquake occurrence affects the likelihood of rupture at a nearby fault. This question was asked when the Landers earthquake occurred on 28 June 1992, after SCEC had found its footing, but before it had grown up. The largest earthquake since 1952 in southern California occurred just 40 km from a major segment of the San Andreas fault considered to be overdue for rupture. At a SCEC emergency meeting held on 13 July 1992, three SCEC groups presented preliminary findings that the San Bernardino Mountains segment of the San Andreas had been brought 5 bars closer to failure, and the Mojave segment had been slightly relaxed. This agreement among independent researchers was captured in the Phase 1 Report.

Forecasting earthquakes has been one of man's dreams for thousands of years. Earthquakes have long captured human imagination with their awesome power and apparent unpredictability. Earthquakes symbolize our relationship with nature. In trying to forecast them, we hope to understand nature and ourselves better.

Acknowledgment

This article was in response to Tom Jordan's question asked at the May, 1995 Advisory Council meeting: "Why should we carry out fundamental studies in earthquake science?" He suggested that the answer to this question may be in what is happening at SCEC, and needs to be articulated for the benefit of the earthquake science community.

To answer this important question I made some comparisons between the current activities at SCEC with what had been discussed at the Lake Arrowhead meeting in 1989 where we decided to create SCEC, and circulated it among SCEC participants requesting comments. This document is an amalgam of comments from Ross Stein, David Jackson, Allin Cornell and Steven Ward on my original attempt.

Appendix

Summary of Scientific Problems Proposed at the Lake Arrowhead Meeting

(A) Regional Master Models:

A-1. Kinematic and Stress Models. These models are needed to explain observed displacement fields, strain, slip on the fault, folding in the crust and flow in the mantle. They can be developed for several time scales. The most useful time scales would seem to be the interval from the immediate future back a few hundred years, and neotectonic time scale of several thousand to several million years. The first model would rely strongly on modern measurements of earthquake recurrence and ground displacement, the second one more on geologic studies. Knowledge gained from the neotectonic model would be applied to shorter term models as constraints on crustal structure, fault locations, and driving forces. The recent work on retro-deformable cross sections in the Los Angeles and Ventura basins would be one set of data that a neotectonic model would have to reconcile. Such models would also likely clarify the kinds of deformation and fault patterns possible near the junctions of major tectonic plates.

A-2. Fault Interaction. Fault interaction is a fundamental issue in tectonics and in the earthquake process. Deformation in the seismogenic upper crust is largely accommodated by an array of brittle faults. The geometry of this array follows specific

patterns that typify the tectonic regime. Two types of interactions between the active faults in the array can be identified. In the spatial domain, faults with different attitudes intersect resulting in perturbation in the shape of the faults, such as bends and lateral steps or jogs. These geometrical singularities along active faults lead to off-fault deformation adjacent to the singularities, which is either extensional or compressional. For strike-slip faults, pull-apart basins or compressional structures are often recognized at bends or jogs, depending on the geometry of the bend and on the sense of fault movement. These structures play a fundamental role in fault segmentation.

In the temporal domain, faults interact because movement on many of the faults are concentrated during earthquake ruptures. A sudden slip on a fault effects stress and strain in the surrounding volume. Thus, the mechanical state of a second fault in this volume is generally affected. Such a fault, for example, can be brought closer to failure by either a reduction of the normal component of stress, and/or by an increase of shear stress along it.

Earthquake ruptures represent mathematical singularities, not only in the evolution of strain and stress, but also in the flow of pore fluids. Thus, faults may also interact by changing fluid pressure conditions. An increase in pore fluid pressure caused by a rupture on one fault may, for example, cause a decrease in effective stress across a second fault and bring this fault closer to failure. An important difference between fault interaction by perturbations in the elastic field versus perturbations in fluid pressure is that the former travel with the speed of seismic waves while the second travels much slower, at the speed of fluid diffusion. Thus, the time scale of fault interaction spans a wide gamut, ranging from the duration of a complex rupture, typically measured in seconds, to the duration of aftershock sequences, which can last many years for large earthquakes. A plate-boundary model where deformation is accommodated by a single fault is clearly not useful in southern California. Near the transition between an oceanic ridge-transform boundary in the Gulf of California and a continental transform in California, this area is characterized by a complex array of faults. Systematic geometric patterns can, however, be recognized. An important hypothesis that needs to be tested is whether systematic spatial patterns of fault interaction correspond to systematic patterns in the temporal relation between the temporal distribution of slip on these faults. The high level of seismicity and the good exposure in southern California offers ideal conditions to study fault interactions in both time and space.

A-3. Block Model and Detachments. The system of master faults and cross faults in southern California is thought to define a series of blocks that rotate clockwise under the right-lateral shear of the transform system. Support for this hypothesis is found in both structural and paleomagnetic data. For example, this model can explain the lack of substantial offset on the master faults at the intersections with cross faults, even where relatively large displacements are inferred on the cross faults. The 1987 earthquake sequence involving ruptures on a cross fault (Elmore Range fault) and the Superstition Hills master fault exemplify the interaction between master faults and cross faults.

A-4. Blind Thrusts; Seismic or Aseismic. A key question is whether the blind reverse faults and their associated decollements beneath the Los Angeles area, which lie at depths of 12 km or more, slip seismically or aseismically. Or to phrase the question in a more mechanically sound way, are the faults presently locked, and if so, will they fail seismically or aseismically? If the faults are currently slipping aseismically they are unlikely to produce large earthquakes, though earthquake rupture from a nearby fault may penetrate into aseismically slipping faults. Study of heat flow and the Miocene history of sedimentation may help estimate the temperature and rheology of rocks at this depth. Additional study of the earthquake cycle for large earthquakes elsewhere in the region, such as the 1857 San Andreas and 1952 Kern County shocks, may also be important for estimating the depths of brittle behavior on short and long time scales.

A-5. Long Range Interaction. A large number of premonitory manifestations of clustering of seismicity prior to large earthquakes have been proposed on

phenomenological ground. One way to improve our confidence in these precursors is to find a physical basis for them that is consistent with experimentally and theoretically determined physical properties of rocks.

Various precursor observations identified changes in seismicity pattern over a large geographic region which are then followed by a large earthquake whose rupture dimensions are much smaller than those of the regions that were activated. At present physical models for this phenomenon are not robust.

A second area that needs attention is the question of long-range interactions between large earthquakes. One study showed a statistically significant number of paired events at the level of magnitude 8 earthquakes, separated by distances of up to 2500 km and times of up to 10 years. Another study identified intermediate sized earthquakes in southern California that were paired with larger subsequent events at distances of up to 300 km and times of up to 3 years. A third study reported 'long distance' aftershocks. Physical models for long-range and long-time coupling seem to rule out stress redistribution with viscous time delays, either through the seismogenic zone, such as those that cause aftershocks, or through the ductile zone of the lower crust. This problem remains unsolved.

(B) Earthquake Rupture Process.

B-1. Fault Segmentation. From the earthquake point of view, ruptures are found to be often limited in a structural recognizable segment. Moreover, ruptures in some segments are found to repeat at relatively regular intervals. Complexities in both the space and time domain are also evident from ruptures of a single segment followed by large ruptures involving the same segment as well as other adjacent segments. Thus, a segment boundary can serve as a barrier in one case and as an asperity in the next rupture. Clearly the issue of segmentation is crucial for modeling and forecasting earthquake ruptures.

B-2. Fault Zone Heterogeneities. To what extent does heterogeneous faulting originate from nonuniformity of the initial conditions of stress and/or strength within the rupture zone, to what extent is it geologically controlled, and to what extent does it represent an intrinsic complexity of rupture originating from the nonlinear dynamics of the process? Are fault zone heterogeneities time and slip dependent or are they persistent features? Can we anticipate the heterogeneity of fault slip in future large earthquakes from studies of surface geology and prior seismicity? Are fault zone heterogeneities time and slip dependent or are they semi-permanent mechanical properties? What is the relationship between fault coupling and slip at depth, and the fault slip and geometries observed at the surface? Why do some fault segments lock and produce large earthquakes while others slip aseismically and only produce moderate and small earthquakes?

B-3. Nucleation, Propagation and Stopping of Rupture. Which geologic features can serve as nucleation points for rupture, and which are capable of stopping rupture? Under what circumstances can more than one geologically-defined segment break in a single earthquake? What is the influence of geologic segment boundaries on strong ground motion? How well can we predict the magnitudes of future large earthquakes from the fault zone features observed at the surface? How are faults loaded? From below or from sides?

B-4. Earthquake Source Scaling. What fundamental differences exist between large and small earthquakes? Can we explain and quantify magnitude and distance saturation of strong ground motion levels on the basis of current source models? What is the physical nature of the transition in earthquake source scaling which occurs at approximately magnitude 3 in southern California? What is the origin of the observed correlation between total coseismic slip and total rupture length? What are the fundamental differences in the physics and dynamics of small earthquakes and large earthquakes?

B-5. Preshocks and Aftershocks. Do large (damaging) aftershocks concentrate around but not within the regions where large amount of slip has occurred in the mainshock? Can we anticipate them? Are these the strong or the weak patches on the fault? Do preshocks exhibit the same behavior? Can we anticipate the heterogeneity of

fault slip in future large earthquakes from studies of prior seismicity and the source rupture characteristics of this seismicity? Where are the strong and weak zones at depth on a fault?

(C) Strong Ground Motion Prediction.

A long-standing aim of seismology is to provide a physical basis and quantitative methodology for forecasting the levels, spectral distribution, and duration of strong ground motion at specific, predetermined sites. Our understanding of the physics of earthquake sources, local and near regional seismic wave propagation, and local site effects has advanced significantly over the past decade, bringing us much closer to this goal. For example, computer modeling combined with empirical Green's function methodology has become an accepted component of seismic safety analysis for critical structures such as nuclear power plants.

As a result, we are now in a position to better identify and quantify ground motion hazards in southern California, and research carried out by the Center will provide the foundation for a greatly improved capability for ground motion modeling in the future. This can be accomplished through: (1) better characterization of potential earthquake sources (location, size, probability of occurrence, style of faulting), (2) improved understanding of the source dynamics of earthquakes, (3) greatly improved knowledge of seismic path effects, through detailed mapping of crustal structure, including lateral variations, and (4) direct seismic measurements and numerical modeling of site effects.

(D) Real Time Seismology.

Substantial damage often occurs at great distances from the epicenter of a major earthquake. Because of the relatively slow speed of seismic waves, it is possible to warn, using radio communication, a region of imminent strong shaking as much as several tens of seconds before the onset of strong shaking. Automated safety responses could be triggered by users after receiving estimates of the arrival time and strength of shaking expected at an individual site. Although the technical feasibility and usefulness of such a warning system has not been thoroughly evaluated yet, it would be desirable to begin serious research of this type of warning system using the data which will be available from the modern broadband seismic network.

There are still many technical problems to be solved before such a system can be put in actual use. These problems include: (1) how to quantify earthquakes as rapidly and accurately as possible; (2) how to update information on the character (e.g. size and mechanism) of the earthquake as the rupture progresses, (3) how to transfer information rapidly to the potential users, and (4) what are the most important source parameters (e.g. acceleration, spectrum, duration) for effective hazard warning.

Highlights of the Education Program of the Southern California Earthquake Center

A Progress Report September, 1994 - September, 1995

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If scientific research is the heart of the Southern California Earthquake Center (SCEC), then education represents the "soul" of the important work performed by the Center. Education is where the lessons learned from the data gathered by scientists is translated and packaged into programs for schools, museums, libraries and for the general public. It is also the place within the research environment that supports and nurtures science literacy for students, teachers and the public. And, it is the place that promotes interest and activity in not only the earth sciences, but all the sciences. SCEC's educational influence in 1995 began to be felt nationally with its undergraduate intern program, its summer program for elementary students, its leadership in Seismic Sleuths project and its exhibit-related projects. With this level of activity, the **SCEC Global Science Classroom** will soon live up to its name.

The goals of the SCEC Global Science Classroom are:

- 1) Plan and conduct science education programs for teachers and students in schools, pre-kindergarten through graduate school.**
- 2) Develop and conduct programs for non-school providers of educational services.**
- 3) Provide information and educational services related to earthquakes for the general public.**

This report highlights the activities of SCEC's educational program from September, 1994 - September, 1995.

Education Goal 1 Services for Teachers and Students

Activities/Undergraduate Colleges and Universities

For Faculty -- Workshop on Undergraduate Earthquake Courses

Postponed from the 1994 workplan, but made up in the 1995 workplan with funds carried over is the curriculum workshop. The target audience was undergraduate earth science and science education faculties from state and private universities and community colleges. "Teaching an Earthquake Course with the Punch of Magnitude 8.0" was a one-day workshop designed to promote communication and community among those who teach earthquake courses for nonmajors or who are planning courses in the near future. Because the workshop had been strategically scheduled at the Southern California Academy of Sciences Annual Meeting May 5-6 in Fullerton, California, participants were able to take advantage of a value-

added feature: complimentary attendance at a SCEC-sponsored scientific symposium, "The Environmental Effects of Urban Earthquakes" presented the day before the workshop. Through the sponsorship of this workshop, SCEC made its first attempt to cultivate and provide services to this audience. The response was gratifying; faculty from at least 18 colleges and universities statewide participated. The products included an "ideal earthquake curriculum" and more ideas for future interaction between SCEC's educational program and college faculty.

For Students -- SCEC Summer Internship Initiative, 1995

SCEC funded 11 students in its second year of supporting undergraduate research. As the program was designed to encourage women and underrepresented minorities to continue their academic careers and later, enter a professional career related to earthquake science, SCEC made progress in achieving a balance by sponsoring projects for six women and five men. In 1994, nine men and four women were supported. In addition to the students' day-to-day research experiences in the lab and field, many participated in a three-day Technical Orientation that was staged in the Owens Valley in California's Sierra Nevada region. Students studied geological features of the area, explored evidence of past earthquakes and volcanoes and completed a geologic mapping activity. In the late summer, SCEC was invited to sponsor a student (or students) to the NSF Conference on Diversity in the Scientific and Technical Workforce, September 21-23. Mandy Johnson, an Asian American intern, was selected to represent SCEC. She will present a poster on *California Earthquake Catalog from 1769-1994* and will serve as a Geosciences Roundtable participant to discuss strategies to increase the participation of underrepresented groups in the geosciences.

The program also welcomed the repeat of Rachel Abercrombie, Lisa Grant as outstanding role models and mentors for the students they supervised. Both had participated in the program in 1994 as Research Advisors.

SCEC Summer Interns, 1995

Intern	Institution	Research Advisor(s)
Windy Brimer	UC Santa Barbara	Marc Kamerling
Andrew Byers	UC Santa Barbara	Jamie Steidl Ralph Archuleta
Heather Hodgetts	University of Southern California	Rachel Abercrombie
Mandy Johnson	University of Southern California	David Jackson, UCLA
Jason McKenna	UC Santa Barbara	Fabian Bonilla Jamie Steidl Ralph Archuleta
Susannah Pazdral	Wellesley College	Marc Legg, ACTA
Ryan Smith	University of Southern California	Michelle Robertson
Donovan Stevens	Caltech	James Dolan, USC
Carmen von Stein	Central Washington University	Lisa Grant, Woodward-Clyde
Mike Watkins	UC Santa Barbara	Kim Bak Olsen
Isabelle Wicks	University of Southern California	Charles Sammis

Activities for High Schools

CUBE for California High Schools

SCEC is in year two of a pilot seismology lab project in Santa Barbara. The centerpiece of the lab is the CUBE, the Caltech-USGS Broadcast of Earthquakes, a real time telecommunications-based earthquake information reporting system. Originally, the CUBE was designed for as an important tool for earthquake emergency response, but its educational potential was recognized by SCEC and is being tested as an exciting and useful science education technology tool for schools. The pilot has generated great enthusiasm at Bishop High School and others as revealed by SCEC's ongoing needs assessment process for educators at all levels and has now been expanded for this second and final year of the pilot to include San Marcos High School and Dos Pueblos High School in the Santa Barbara area. Based on the projected success of the pilot, discussions have begun with the California Department of Education's Educational Technology Office about expansion plans for many more high schools throughout the state in the coming years.

Seismic Sleuths Review Panel

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

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

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

Seismic Sleuths National Leadership Institute

The 1995 *Seismic Sleuths* National Leadership Institute was conducted from July 17-21. 24 persons participated in the Institute, which was held at the National Emergency Training Center in Emmitsburg, Maryland. Support for the training course was provided by the Federal Emergency Management Agency (FEMA). Participants ranged from secondary classroom teachers to emergency management personnel to museum educational staff and earthquake research and educational experts.

The stated objectives of this Institute were:

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

"LARSE on Line"

This multimedia package will take advantage of the important data derived from the October, 1994 LARSE (Los Angeles Regional Seismic Experiment) funded in part by the National Science Foundation. The purpose of LARSE was to take a "CATscan" of the Los Angeles basin so as to find out more about hazardous fault zones that dissect the region. In the first year of anticipated multi-year development, a LARSE Handbook will be prepared to explain the exploratory seismology methods used during the experiment and to provide guidelines for the use and manipulation of data in the classroom. SCEC will also review and script appropriate segments of the extensive video captured during the experiment. In the second year the video material and particular data sets will be prepared and packaged for transport over the Internet and other modes of delivery to high schools, (community colleges and undergraduate institutions) to complete this multimedia program. "LARSE on Line" will be an original SCEC educational product.

For High School and Elementary Students

Junior Academy Research Sponsorships

The Southern California Junior Academy of Sciences is an organization of several high school science programs in the area that promote the development of scientific research skills. Three of the member programs are NSF Young Scholars Programs. These include the Consortium Young Scholars managed by USC, the Fullerton Young Scholars at California State University, Fullerton in Orange County and the Museum Research Apprenticeship Program at the Museum of Natural History of Los Angeles County. An additional program -- and the prototype for some of the Young Scholars programs in the area -- is the privately-funded Research Training Program. As a program sponsor, SCEC provided and supported lab or field research opportunities for 7 students in the Research Training Program. SCEC primarily sponsored those students conducting research projects in the earth and physical sciences. Please note: Nearly 40% of the Westinghouse Science Talent Search Semi-Finalists for 1995 were members of the Junior Academy.

Summer VINE Program

Over 1,000 elementary students learned about the natural and built environment (including geology and earthquake science and safety) in this neighborhood environmental education pilot program. Loosely modeled after the VINE Network, an inner city environmental education program managed by the North American Association for Environmental Education, this program guided students through *Tremor Troop* elementary earthquake education activities each week during the program with the help of 14 Science Activity Leaders, all of whom were high school students from minorities including African American, Hispanic American and Asian American. The program was conducted for six weeks in South Central inner city Los Angeles Boys and Girls Club and USC neighborhood school sites -- conducted in neighborhoods with high populations of African American and Hispanic students. The program was supported by a combination of funding from the Southern California Academy of Sciences, Chevron Oil Co., ARCO, FEMA, the City of Los Angeles Summer Youth Employment and Training Program and the USC Neighborhood Outreach Program. The program also supported four earth science graduate students as worksite supervisors and employed an African American elementary teacher as program coordinator.

Education Goal 2 Activities for Non-Formal Education Services Providers

Exhibits for Museums

Responding to FEMA's interest in developing a set of portable exhibits on that would interpret earthquake phenomena for public audiences, SCEC solicited proposals from a limited number of science exhibit developers in its 1995 grant RFP. Two proposals were submitted to develop both interactive mechanical and electronic exhibits prototypes. These would be the first

in a series that might ultimately include exhibits on a range of natural phenomena/hazards (floods, tornadoes, etc.) over a multi-year period. The exhibits would be designed in a manner that would allow for travel and display at museums, libraries and even shopping malls.

Multimedia Programs for Museums

Additional interest in SCEC's educational capabilities came in the form of an invitation to participate in the cooperative development of educational activities related to "The Restless Earth" episode on earthquakes in the "New Explorers", a PBS science series. Under this project SCEC will be working the Discovery Science Center in Orange County California which, in turn will be working collaboratively with the Association of Science and Technology Centers (ASTC, a national organization of science museums).

Education Goal 3 Information and Educational Services Related to Earthquakes for the General Public.

Groundwater Festival

SCEC and the Southern California Academy of Sciences teamed to premier the "Great Groundwater Game" at a one-day Groundwater Festival sponsored by the Water Replenishment District of Southern California. The unique event took place at Cerritos College, October 22. The visually exciting and highly interactive game gave festival-goers a chance to learn about the relationship between groundwater resources and earthquakes, including the role of earthquakes in causing liquefaction to the role quakes play in creating surface-water lakes called sag ponds. The game was played on a gigantic 400 square feet in area that attracted scores of players and media alike. Players in the game acted as the markers, moving about the board according to the responses they gave to questions posed by the game's leader.

Earthquake Fair

On April 21-22, SCEC staffed a booth and conducted educational activities for schools and the public at the Los Angeles Earthquake Fair.

**The Southern California Earthquake Center (SCEC)
Knowledge Transfer Program**

Jill Andrews

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SCEC Mission Statement

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.

Knowledge Transfer

SCEC administration actively encourages collaboration among scientists, government officials, and industry. Users of SCEC scientific products (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. (See Figure 1.)

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.

History of the SCEC Knowledge Transfer program; Tasks and Projects in Progress, 1995:

The Center was established in 1991. Between 1991 and 1993, Professor Karen McNally of UC Santa Cruz worked closely with the Governor's Office of Emergency Services, to develop an education and outreach program. Some of the significant contributions were:

- Development of an education and outreach infrastructure—writing a mission statement, developing education and outreach plans.
- Recommended to SCEC Board that 10% of Center's overall funding be devoted to E&O (this was adopted).
- Recommended that E&O have working group status equivalent to the research working groups, within the Center's overall structure (this was also adopted)
- Defined some of the staffing needs and their recommended place within the Center's organization structure (these recommendations were also followed, leading to Center's contracting of two full-time Directors; one for education (currently Curt Abdouch) and another for knowledge transfer (currently Jill Andrews). Both positions are members of the Center's Steering Committee.

From February 1994 - January 1995, Laurie Johnson of Spangle and Associates joined SCEC as a consultant and worked to further define the role of knowledge transfer within the Center's organizational structure.

In August 1994, the SCEC Board endorsed the concept for a Research Utilization Planning Process. Center directors assumed that our priority users were those responsible for risk reduction in the built environment, land use, and disaster preparedness and response.

Following Yin & Moore's study on knowledge transfer in the natural hazards field, which encourages "rich and direct communication between knowledge producers and users throughout the design and conduct of the research project", a model was developed to illustrate a knowledge transfer strategy for the Center. (See Figure 1.) We have encouraged success of this effort by having full scientific participation throughout the planning process and in implementing the plan.

The first task performed by the Research Utilization Council (RUC) was inventorying the knowledge being produced by SCEC. Center's working group leaders were asked to define:

- vision/goals of their working groups;
- examples of project completed by the groups;
- highlights of the 1995 plan and 5-year goals;
- significant hardware capabilities of the group; and,
- dissemination methods.

Based on what they heard from the Steering Committee, RUC members were asked to comment on four points:

- priority users;
- local candidates/contacts;
- communication methods; and,
- other linkages, opportunities for interfacing with users, joint projects, etc.

The goal was to begin to develop the network for reaching our users and clarifying their input on specific needs. The RUC identified two groups of users--information users and knowledge users (Fig. 1).

- Knowledge users were defined as groups that we should target for product development.
- Information users were defined as groups who need earthquake information but are not necessarily the target groups for product development.

Information users were identified and grouped by categories:

Building Construction and Design Group. Comprised of earth science and engineering professionals who need earthquake information to reduce risks to structures.

Lifelines Construction and Design group. Comprised of earth science and engineering professionals who need information to reduce risks to lifelines.

Land Use/Hazard Mapping group. Comprised of earth science professionals who need earthquake information to assess and map land use hazards.

Specific Tasks, Products and Projects in Progress:

- Workshop for Research Utilization Council and Representatives from End-User Groups, Industries, and Private and Government Agencies. Purpose of the workshop series (October and November, 1994; June, 1995) was to define the role of knowledge transfer within the Center's organizational structure, and provide answers to three fundamental questions:

Who are the Center's priority user groups?
What knowledge do these user groups need and in what form?
How can the Center best communicate with these groups?

Priority Product and Project Lists identified by the three representative end user groups during the final workshop are available on request.

- Insurance Industry Workshops. Purpose of the first workshop (November 9-10, 1995) is to establish dialogue among scientists, insurance industry leaders, risk assessment/modeling representatives, and public officials. Workshop may develop into future continuing education courses or workshops on earthquake risk assessment for insurance industry underwriters and actuaries, to be developed under joint sponsorship of SCEC and the Insurance Education Association. (Registration form available on request; abstracts available following workshop.)
- GIS Users Workshops. Purpose of these workshops is to provide venues for discussions among scientists and end-user groups regarding consensus issues; integration of multiple databases; use of software; 2-D, 3-D issues; methods of updating and maintaining databases. (GIS Users Workshop Report by L. Grant and S. McGill available on request.)
- Vulnerability Workshops. Purpose of these workshops is to promote information exchange with southern California city and county officials whose concern is the effect of large urban-area earthquakes on the built environment.
- Media Workshops. Purpose of these workshops is to establish communication with radio, TV, and print media; discuss guidelines for efficient and informative knowledge transfer during and after significant earthquakes; present short, concise reviews of basic geology of the area.
- Field Trips. Series of local (one-day) tours led by experts on major active faults of southern California. SCEC also publishes and disseminates field trip guides.
- Quarterly newsletter. The SCEC Quarterly Newsletter consists of informative, brief articles highlighting ongoing research; lists new publications; announces Center-sponsored activities, workshops; provides an information resource guide. (Volume 1, No. 1, available through WWW; Volume 1, No. 2, available on request.)
- Reports. The Center's principal products to date have been two published "Phase n" reports:

Phase I: Future Seismic Hazards in Southern California: Implications of the 1992 Landers Earthquake Sequence, published in November, 1992; and

Phase II: Seismic Hazards in Southern California: Probable Earthquakes, 1994-2024.

SCEC Knowledge Transfer will work to produce various "translations" of the Phase "n" reports for specific end-user groups (e.g., property and casualty insurance underwriters; civil and structural engineers; geotechnical engineers; engineering geologists; urban planners; the general public). (Copies of "Seismic Hazards in Southern California: Probable Earthquakes, 1994-2024" and "Putting Down Roots in Earthquake Country" are available on request.)

- Provide World Wide Web and Internet access to SCEC infrastructure centers' data and other earthquake-related information. Construction, implementation and advertisement of SCEC Home Page and SCEC Core Institution Pages took place in summer, 1995.

SCEC WWW Page URL: <http://www.usc.edu/dept/earth/quake>
Internet Address, General Information: ScecInfo@usc.edu

Partnerships

The Center actively seeks to continuously promote and maintain collaborative and mutually beneficial partnerships with its core institutions, affiliated institutions, local, state and federal government agencies, and business and industry. Examples (not a complete list) of SCEC's partnering entities:

Government:

U.S. Geological Survey
California State Division of Mines & Geology
Applied Technology Council
Federal Emergency Management Agency
California State Governor's Office of Emergency Services
California State Seismic Safety Commission

Professional Organizations:

American Society of Civil Engineers
Association of Contingency Planners
Association of Engineering Geologists
Earthquake Engineering Research Institute
Insurance Institute for Property Loss Reduction
Seismological Society of America

Educational:

Earthquake Engineering Research Center, U.C. Berkeley
National Center for Earthquake Engineering Research, Buffalo, New York
University of Delaware Disaster Research Center
Natural Hazards Center, Boulder, Colorado

The goal is to promote ownership among the participants by reaching consensus as to overall priorities for product development, improving communication to users, and establishing the role of SCEC. We see this as an iterative process; both scientists and end-user representatives are educating each other.

We believe SCEC will, in the next five years, make a significant contribution to society through a transportable Knowledge Transfer program which promotes the application of earth sciences and engineering practices to earthquake hazard reduction.

The Research Utilization Council and End Users' Workshop

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The Research Utilization Council and End Users' Workshop took place at USC on 20 June 1995. Results of the voting procedure to determine highest priority items came from a list of 99 products and projects previously identified by the group. An interim report, prepared by Laurie A. Johnson, AICP, and SCEC Director for Knowledge Transfer, February - December, 1994, documents Research Utilization Council (RUC) activities and process up to 1 January 1995. Copies of the interim report, as well as the 99 items listed according to category, are available through the SCEC Knowledge Transfer Office.

The purpose for the 20 June meeting was to establish both short- and long-term priorities, with realistic implementation time frames. Summary documentation will be presented at the SCEC Annual Meeting. A revised version of this report, following submission to and discussion by the SCEC Steering Committee on 9 August, will be submitted to the Board of Directors.

Raw data for all categories, all criteria are available on diskette in Excel 5.0 for Macintosh. A summary of top choices by Focus Group and Aggregate Group is available in Word 6.0 for Macintosh on diskette or hard copy.

1995 Abstracts
for the Annual Meeting of the
Southern California Earthquake
Center

SCEC's Global Science Classroom: A Summary of the Educational Activity of the Southern California Earthquake Center for 1995

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In its second year of development and operation, the educational program of the Southern California Earthquake Center (SCEC) has refined its target audiences, initiated new projects and has added new features to ongoing projects. The programs highlighted are the SCEC Summer Internship Initiative; the Southern California Junior Academy of Sciences; the Undergraduate Faculty Workshop; "Teaching an Earthquake Course with the Punch Of Magnitude 8.0"; FEMA's Seismic Sleuths National Leadership Institute and the Summer VINE project. The summary demonstrates the relationships designed in and between projects in the program and provides evidence of an earth sciences education "pipeline" being created at the high school and college level which supports students academically and financially.

Dynamic Healing of Fracture and the Self-Organization of Earthquakes

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The simulation of long-term seismicity under the influence of self-organization is highly sensitive to the state of residual stress after recent earthquakes. This residual stress, in turn, is influenced most strongly by the mechanism of the healing of slip on the slip surface. We construct a two-dimensional dynamic continuum crack model, based on the boundary-integral method of Kostrov, to investigate the influence of the freezing of slip on the self-organization of earthquakes. We find that as healing proceeds from one edge of a dynamic crack, large kinks in the residual stress can result at locations where stress waves radiated from the opposite edge intersect the locus of healing. As a result, on faults with homogeneous fracture strengths, earthquakes of a given size tend not to recur at the same sites; rather, the fault is broken up into smaller and smaller segments until a steady state of small events is attained whose seismic moments fit satisfactorily the Gutenberg-Richter distribution. Localization of earthquakes may be possible in this two-dimensional dynamic model for faults with highly heterogeneous distributions of fracture strengths.

Southern California Earthquake Center: Knowledge Transfer

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The SCEC administration actively encourages collaboration among scientists, government officials, and industry. Users of SCEC scientific products (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:

- Final Workshop and Report, Research Utilization Council and Representatives from End-User Groups, Industries, and Government Agencies.
- Insurance Industry Workshops.
- GIS Users Workshops.
- Vulnerability Workshops.
- Media Workshops.
- Field Trips.
- Quarterly newsletter.
- WWW SCEC Home Page.
- Publications; Scientific Reports

Geodetic estimates of Interseismic and Coseismic Motions in the Southern San Andreas System, 1986-1995

**R. A. Bennett, B. H. Hager, T. A. Herring, R. W. King, S. C. McClusky
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The velocity field for southern California estimated by Feigl et al [JGR 98,21677, 1993] from GPS and VLBI measurements was strong for the western Transverse Ranges but weak south of the Ventura basin. GPS data collected by Caltrans, county agencies, and SCEC investigators since 1986 allow an extension of coverage south to the Gulf of California, northern Baja, Mexico. We present a progress report on the integration of VLBI, GPS, and EDM data for this region, including estimates of secular velocities and coseismic displacements from the Joshua Tree, Landers, and Northridge earthquakes.

Seismicity Patterns Along Complex Fault Systems

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We discuss numerical simulations of slip evolution along cellular strike-slip faults in an elastic half-space. The models correspond to discrete fault systems embedded in a 3D elastic matrix. The simulations are performed in a quasi-static fashion; inertial effects are approximated by dynamic overshoot during brittle slip episodes. The models incorporate brittle and creep deformations; the net fault zone deformation rate is the sum of creep rate and frictional slip rate. The creep properties are prescribed in terms of coefficients characterizing a power-law dependency of creep-slip-rate on stress. The brittle properties represent different levels of fault zone disorder. Two idealized cases of fault systems having brittle properties corresponding to different extreme states along an evolutionary path of a fault are considered: (1) strongly disordered systems characterized by a wide range of size scales, representing immature fault zones and extended spatial domains, and (2) relatively regular systems having a narrow range of size scales, representing mature highly-slipped faults. The results indicate that the range of size scales characterizing fault zone heterogeneities has important manifestations on the seismic response of the fault. A narrow range of size scales leads to strong enhancement in the rate of occurrence of large

earthquakes with respect to power law extrapolation of low magnitude seismicity (i.e., the characteristic earthquake distribution), and quasi-periodic temporal distribution of large events (as in, e.g., the seismic gap hypothesis). On the other hand, a wide range of size scales leads to power law frequency-size statistics over a broad magnitude range (i.e., the Gutenberg-Richter statistics), and random or clustered temporal distribution of large earthquakes. The simulations indicate that treatment of the various forms of observed frequency-size and temporal statistics of earthquakes can be unified through the concept of range of size scales characterizing fault zone heterogeneities. This has a clear physical interpretation in terms of structural properties of a given fault zone or lithospheric domain, and is supported by fault and earthquake data [e.g., Wesnousky, BSSA, '94].

Activities at the Scripps Orbit and Permanent Array Center

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A program of continuous GPS measurements along the Pacific and North America plate boundary in southern California was initiated in 1990 as a NASA pilot project with four tracking stations. Today the Southern California Integrated GPS Network (SCIGN) consists of more than 30 permanent stations with an active ongoing densification, particularly in the Los Angeles Basin, and plans for an order of magnitude increase in the number of stations. The array is operated jointly by the Scripps Orbit and Permanent Array Center (SOPAC), the Jet Propulsion Laboratory, the U.S. Geological Survey/Pasadena, and county and local surveying offices.

SCIGN has pioneered continuous, near real-time geodetic measurements with respect to a consistent global reference frame which is critical in dynamic southern California. This achievement was made possible by the parallel development of the global GPS tracking network, now under the umbrella of the International GPS Service for Geodynamics (IGS), and major improvements in GPS instrumentation and analysis software. SCIGN plays two major roles in the study of active tectonics in southern California. It is a reference network for ongoing GPS field measurements, providing base stations, links to stable North America and the International Terrestrial Reference Frame. In addition, it provides temporally dense geodetic measurements of crustal motion over periods of minutes to years and the ability to distinguish possible temporal variations in regional crustal strain.

SCIGN related activities at SOPAC are highlighted in this poster, including site maps, time series results for the Northridge earthquake, and a description of new SOPAC products. Most of the material is also available on the World Wide Web (<http://jon.ucsd.edu>).

Does the Physics of Critical Phenomena Apply to Regional Seismicity?

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It has been suggested that the mechanical failure of heterogeneous solids shares many characteristics of critical phenomena such as magnetic and chemical phase transitions. If this analogy is appropriate for the study of regional seismicity, then there should be several observable consequences.

1. Regional seismic activity should show power-law scaling before and after an earthquake. Under certain conditions, the critical exponent can be complex, leading to log-periodic fluctuations in the scaling.

2. One condition which can lead to a complex critical exponent occurs when the physics is expressed on a discrete hierarchical fractal structure. If the regional fault network is a discrete fractal, then log-periodic fluctuations should appear in the measured fractal capacity dimension. This discrete hierarchy should also produce periodic fluctuations in the Gutenberg-Richter frequency-magnitude curves.

3. The physics of critical phenomena also makes general predictions about the correlation length of seismic activity before and after a large earthquake. The scale of spatial clustering should increase leading up to the main shock, and then decrease during the aftershock sequence.

We present evidence that all three of these phenomena are observed before and after large earthquakes in California.

Strong-Motion Site-specific Amplification Factors for Southern California

Andrew Byers

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We updated the existing SCEC/ICS strong-motion database to include response spectral ordinates and site-specific amplification factors for sites recording events since the 1933 Long Beach earthquake up to and including the 1994 Northridge quake. Response spectral acceleration, velocity, and displacements were first calculated for each event at each site in the database. The attenuation relation of Sadigh et al (1994) was used as a reference model for a site-specific comparison of the site's peak ground acceleration and specific response spectral values. Strong-motion data is compared with this attenuation relationship in order to find site amplification or de-amplification factors. We also calculated amplification factors using the average rock response spectral values as a reference. The results of these comparisons will be available through the strong motion database. The records will consist of four amplification factors at each site for all available events within the southern California region. The four amplification factors are at periods of 0.1, 0.3, 1.0, and 3.0 seconds. The sites were chosen because of their structure type and geographical position. Sites were limited to include only those located in the southern California region (with a maximum latitude of 36.0 and a minimum latitude of 32.0) and those that could be classified as free field. These results will help to produce a more complete understanding of seismic hazards for the southern California and assist in the further study of seismic events.

GPS, Earthquakes, the Ionosphere, and the Space Shuttle

Eric Calais and Jean-Bernard Minster

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During its ascent through the atmosphere and ionosphere, the Space Shuttle generates powerful acoustic perturbations. Because of the coupling between neutrals and electrons at ionospheric altitudes, these low frequency acoustic perturbations induce variations in the ionospheric electron density. Similarly near-surface seismic sources that generate large vertical displacements of the surface can excite infra-sonic waves which propagate upward to the ionosphere and also induce ionospheric perturbations. We show

that GPS data can be used to detect such signals after the STS-58 Shuttle launch, and after the January 17, 1994 Northridge earthquake.

Reflectivity Structure Beneath the 1994 Northridge Aftershock Zone

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The main purpose of this work is to depict regional fault structures by imaging the reflectivity structure beneath the 1994 Northridge aftershock zone. This is feasible through the use of exploration seismology techniques. Our approach is to combine efficient stacking and migration algorithms and simple trace editing to image the location, depth, and geometry of buried faults based on aftershocks of the 17 January 1994 Northridge, CA, earthquake. This will enable us to test the existence of major structures proposed in balanced cross sections.

Our previous common-midpoint (CMP) stacked sections depicted major reflective structures and hinted at prominent structure beneath and north of the Northridge epicentral area. Further processing of A-quality aftershocks lying within 3 km depth identifies prominent shallowly-dipping features between 5-10 s (two-way time).

As we seek to ignore the effects of focal mechanisms, wavelet phase, and absolute amplitude variations, data preprocessing and signal conditioning includes muting, trace balancing and gain control, bandpass filtering and stacking methods other than simple summation. Also, we limit the data set to 200 km distances and 30 s duration to include wide-angle reflections well-separated from Pg and Sg but between the two arrivals. Muting outside the window between Pg and Sg arrivals permits us roughly to include only compressional direct and reflected arrivals (mostly Pg, PmP and S to P converted energy).

In addition to the CMP stacked sections, we have just begun three-dimensional prestack depth migration trials with the flat-layer P wave velocity model for southern California. Further work will focus on the use of existing, more complex velocity models as well as statistical analyses to help validate imaged reflectors and depict possible fault locations and other major structures.

Finite Element Modeling of Interacting Blind-Thrust Faults: Two-Dimensional Case

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The Los Angeles Basin is thought to be underlain by a series of concealed thrust fault systems. Studying these blind-thrust faults and their mechanical interaction with overlying folds and adjacent strike-slip faults is important in order to understand the evolution and tectonics of the region, and could contribute significantly to the assessment of earthquake hazards in the basin. The long-term goal of our research is to construct a 3-D model of earthquake faulting using a finite element approach. Our purpose is to simulate numerically the blind-thrust faulting process in the Los Angeles basin and we hope to advance our understanding of the causes and timing of the 1994 Northridge rupture. Our preliminary 2-D study has been focused on the time-dependent stress changes caused by pre-Northridge moderate-size earthquakes and their effects on the Northridge rupture site. We believe this should be a significant advance over the current static models of Coulomb

stress changes [e.g. Stein et al., 1994]. Our 2-D model consists of a ~15 km thick brittle/elastic layer overlying a ductile (viscoplastic) half-space. We seek to understand how the static Coulomb stress changes are affected by the time-dependent effect of the brittle/ductile interaction, and to elucidate details of the time-dependent interaction between the Northridge rupture and pre-Northridge events. Such results will help us understand better the role of stress triggering in controlling earthquake occurrence in areas such as the Los Angeles basin.

Scenarios of Time-history Generation and Effects of Local Site Characteristic on Ground Acceleration

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The objective of this study is to present results of time histories modeling of earthquake scenarios in the Los Angeles Basin. The ground motion records calculated by a time-history working group were first validated with the records from the 1992 Landers earthquake and the 1994 Northridge earthquake. Quantitative comparisons were made for both time duration and response spectral values. The bias calculated from all groups is smaller than a factor of two. Five earthquake scenarios (M7.9 on the San Andreas, M6.75 and M7.25 on the Palos Verdes fault, M6.75 and M7.25 on the Elysian Park fault) were selected and two CDMG station sites were chosen for this study. The sites are the Rolling Hills Estate (denoted as RHE, CDMG#14405) and Temple and Hope (denoted as TAH, CDMG#24611). We tested these physical modeling results against empirical attenuation relations. For a magnitude 7.25 scenario earthquake on the Palos Verdes fault, for the near fault zone site RHE, the empirical models show lower predictions by a factor of two compared to physical predictions. In the other hand, for the site TAH, both empirical and physical models match well for the whole frequency range. Non-linear one dimensional site response analysis also been used to modify selected time histories to reflect representative site soil conditions.

Mapping of the 1994 Northridge Earthquake Fault and the Santa Susana Mountains Anticlinorium, Southern California

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The 1994 Northridge earthquake fault (Pico thrust) and Santa Susana Mountains anticlinorium have been mapped from balanced cross sections based on surface and well data. The earthquake hypocenter lies below the San Fernando Valley synclinorium which joins the Santa Monica Mountains and Santa Susana Mountains anticlinoria. We have postulated that the anticlinoria are crustal-scale fault-propagation folds underlain by active thrust faults. The Northridge earthquake occurred along the south-dipping Pico fault which builds the Santa Susana Mountains anticlinorium, and cross sectional analysis and mapping of the anticlinorium provides important information on the extent and slip of the Pico fault. The anticlinorium and fault extend eastward from the Simi Valley under the northwestern San Fernando Valley to at least the city of Glendale. The north limb of the anticlinoria is

well documented by a continuous zone of steep bedding dips, 2-3 km wide and along the north side of the Santa Susana Mountains and south limb of the Merrick syncline. The Verdugo and San Rafael Mountains are the crystalline rock core of the anticlinorium. The south limb of the anticlinoria outcrops at Laskey Mesa in the western San Fernando Valley, but much of the south limb is concealed beneath the alluvial cover of the San Fernando Valley where it is deformed by less significant faults and folds. Our mapping suggests that only the western half of the Pico fault moved in 1994 and the eastern half may pose a significant seismic hazard to the northern Los Angeles basin.

Latest Pleistocene to Early or Mid-Holocene Age of Most Recent Surface Rupture on the Hollywood Fault, Hollywood, California: The Ozzie and Harriet Trench

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A N-S transect of nine adjacent, 70 cm-diameter boreholes drilled just west of downtown Hollywood reveals that the most recent surface rupture on the Hollywood fault occurred during latest Pleistocene to early or mid-Holocene time. Direct examination of the boreholes, which extended to a depth of 10 to 13.5 m, indicates that several near-vertical (75°-85°N) fault splays displace a latest Pleistocene paleosol at 7.5 m depth one meter down to the north over a 3 m-wide zone. A prominent gravel bed at 5.8 m depth extends unfaulted across the fault zone, indicating that the most recent surface rupture occurred during deposition of the intervening unit. The mountain-side-down separation of the 7.5 m paleosol and the near-vertical dip of the fault splays confirm that the Hollywood fault is primarily a strike-slip fault. Although not as well documented, the borehole data suggest that the penultimate event ruptured through a prominent paleosol at 11 m depth, but did not displace the 7.5 m paleosol faulted by the most recent event. Radiocarbon dates recovered earlier from presumably correlative units on the same fan suggest that the 7.5 m paleosol dates to ~15 to 20 ka. ¹⁴C age dating of detrital charcoal and bulk-soil MRT samples collected from the boreholes will allow us to substantially narrow the age ranges of these events.

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

Seismic Hazards in the Santa Barbara Channel Using High Resolution Seismic Reflection Data and Dated Horizons From ODP 893

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A grid of high-resolution seismic reflection data has been correlated to horizons identified in ODP 893A drilled in the Santa Barbara Channel. These horizons have been accurately dated using oxygen and carbon isotopes (Kennett, 1995). The age of the oldest sediment penetrated by the core sample is late Pleistocene. Several younger horizons can be correlated with coherent reflections identifiable in the seismic data. Any near-seafloor deformation that affects these horizons must be considered potentially active. This dated seismic stratigraphy can be used to estimate the rate of slip on faults, the relative ages of submarine slides and unconformities, and the development of growth strata associated with fault-related folding. This information can be used to improve understanding of local tectonic processes and seismic hazard estimation in the channel. Based on core-hole stratigraphy, a strong continuous reflection that was mapped throughout much of the channel, is dated at approximately 120,000 years. Measurable time separations of this horizon have been identified across several possible fault (?) structures and were converted to depth using velocity-depth relations for P-waves in silt-clay and turbidites (Hamilton, 1979).

***SCEC Summer Intern**

Spectral Amplification in a Sediment-Filled Valley Exhibiting Clear Basin-Edge Induced Waves

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Various site response estimates are presented for a linear array deployed in the Coachella valley, California during the Landers aftershock sequence. This study represents a case where the response is clearly dominated by basin-edge induced waves. Average sediment to bedrock spectral ratios for long S-wave windows exhibit amplification factors as high as 18 below 7 Hz. The deep basin structure, which gives rise to the obvious multidimensional effects, produces a fundamental resonant peak below 0.6 Hz. The frequency of this peak shifts between basin sites as the depth to bedrock changes. Above 0.6 Hz, where the largest amplifications occur, the response is remarkably similar between sites and appears to be dominated by a near-surface layer that is relatively uniform across the valley.

Sediment to bedrock spectral ratios computed using shorter windows, that exclude the basin-edge induced waves, imply that the multidimensional effects are significant only below ~4 Hz where they increase amplifications by a factor of ~2. Spectral ratios computed using coda windows, taken at 2Ts, exhibit amplifications that are an average factor of 1.7 greater (between 1 and 4 Hz) than those of the S-wave estimates. This discrepancy does not improve by taking coda windows later at 4Ts. Sediment to bedrock spectral ratios of ambient seismic noise do not look like the S-wave estimates. However, horizontal- to vertical-component noise ratios exhibit clear peaks near the fundamental resonant frequencies of both the deep basin structure (below 0.6 Hz) and the suspected near surface layer (between 0.8 - 1 Hz).

Variable Spreading Rates in the Gulf of California and Major Deformation in Southwestern California

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Published marine-magnetic anomaly data related to sea-floor spreading in and just outside the Gulf of California were used to create a plot of spreading-rate velocity as a function of age. The resulting curve shows significant and continuous spreading rate variations of several centimeters per year over the last ten million years (almost a factor of three variability). These variations correlate roughly with major tectonic events in southwestern California, including the inception of the San Andreas, San Jacinto and San Gabriel faults, the development of the western San Bernardino arch system, and the onset of contraction in the Los Angeles Basin. These correlations suggest that regional-scale plate tectonic forces may be an important factor in the local tectonic development of Southern California.

Damage Caused by the 1994 Northridge Earthquake and Site Amplification Effects from Aftershocks

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During the January 17, 1994 $M_w=6.7$ Northridge earthquake, Sherman Oaks and mid-Santa Monica experienced much greater damage than neighboring regions at similar distances from the epicenter. To understand the cause of the concentrated damage, we installed an array of ninety-eight seismic stations to record aftershocks in the two heavily damaged areas as well as along two profiles across the San Fernando valley and the northwestern part of the Los Angeles basin.

The analysis of peak P- and S-wave amplitudes and Fourier spectral ratios for S- and S-coda-waves from 32 aftershocks indicates that the enhanced damage in Santa Monica is explained in the main by focusing due to a lens structure at a depth of several km beneath the surface, and having a finite lateral extent. The diagnosis was made from the observation of late-arriving S-phases with large amplitudes, localized in the zone of large damage.

We show that the focusing, and hence the large damage in Santa Monica was highly dependent on the location of the Northridge event and that an earthquake of similar size, located as little as one source dimension away, would not be likely to repeat this pattern.

TRANSTENSIONAL FAULTING WITH LONG RECURRENCE INTERVALS THROUGH THE WHITTIER NARROWS AREA, ROSEMEAD, CALIFORNIA

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The Whittier fault (WF) is a strike-slip fault through the Puente Hills that is accommodating a minimum of 2-3 mm/yr of dextral strain. The Alhambra Wash fault (AWF), along the western margin of the Whittier Narrows (WN) east of Los Angeles, is

interpreted to be the youngest fault in an extensional zone where the WF steps northward of the Montebello Hills. The AWF forms a subtle scarp across the youngest terrace surface of Alhambra Wash (Treiman, 1991). The fault was excavated in 3-D and a cobble-filled, channel thalweg was used as a piercing point across the fault. Based on soil profile development, the channel is estimated at about 35-40 ka. Reconstruction of the channel yields offsets of 6-10 m right-lateral and 3 m vertical- slip rates of 0.2 ± 0.1 and 0.08 ± 0.01 mm/yr, respectively. Only three or four paleoseismic events are interpreted in the stratigraphic record from increasing displacement, fault truncation, colluvial wedges, and buried soils. The last surface-rupture created a 0.3-0.4 m vertical offset of a cambic soil horizon, estimated at <3-4 ka. This soil and scarp are buried by a thick, cumelic A-horizon that truncates the fault. However, a younger event created an en-echelon set of dilational fissures that are filled with the A-horizon soils. Three bulk soil-carbon samples from the base of the A-horizon yielded 14-C (minimum) ages between $1,130\pm 40$ and $1,660\pm 50$ BP. Assuming 0.3-0.4 m vertical displacement as a typical event, a recurrence interval of about 5,000 years is necessary to achieve the measured vertical channel offset-an interval which would also require 1 m lateral displacements. We speculate that the displacement events on the AWF record large cascading earthquakes when the WF ruptures through WN, and that the latest surface-fissuring event is the result of a smaller WF earthquake that terminated in the WN dilational step at least 1,600 years ago.

ACTIVE TECTONIC STRUCTURES IN THE EASTERN LOS ANGELES BASIN

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The Los Angeles basin lies at the transition from strike-slip dominated tectonics in the south, to fold-thrust tectonics in the north. The Elsinore fault is feeding north-vergent plate motion into the eastern LA basin at a rate of about 4-6 mm/yr. At least half of this strain is accommodated as pure right-lateral strike-slip along the Whittier fault with the remaining strain apparently being consumed in the growth of folds. Alluvial fan sediments shed from the uplifting Puente Hills are anticlinally deformed by south vergent compression along blind thrusts into an en-echelon fold belt lying subparallel to and south of the Whittier fault. The Coyote Hills, Kraemer, Olive, Peralta Hills, and several other unnamed anticlinal structures comprise this fold belt. Quantitative tectonic geomorphic analysis is being used to understand the neotectonic deformation in this densely urbanized area of the Los Angeles basin. Geomorphology, therefore, becomes the investigative tool to provide spatial and temporal constraints on active tectonic structures that are inaccessible by the traditional paleoseismic tool of trenching and detailed geologic logging. Geomorphic mapping of the pattern of fluvial deformation within the folds indicates that there is a rich temporal record of progressive deformation preserved within the chronology of stream terraces and long-channel profiles. Seven fill and strath terraces within the antecedent Santa Ana River canyon, age-correlated to the marine eustatic record of glacial-interglacial climatic fluctuations, record a 500 ka uplift rate of 0.57 ± 0.05 mm/yr for the eastern Puente Hills.

LATE QUATERNARY SLIP RATE OF THE WHITTIER FAULT IN THE SOUTHEASTERN LOS ANGELES BASIN, CALIFORNIA

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The Whittier fault is a right-lateral, strike-slip fault, that is transferring the Elsinore fault's 5 ± 1 mm/yr neotectonic strain directly into the Los Angeles basin. All streams crossing the fault are right-laterally deflected. At Olinda Creek in Brea, two parallel faults carry most of the slip, as indicated by the abrupt double offset of the creek. Each fault strand offsets the channel valley by a similar amount suggesting relatively even partitioning of strike-slip. These two faults bound a 30 m wide, elongate pressure ridge; the faults are expressed in trench exposures as a positive flower structure, with opposing dips presumably merging at relatively shallow depths into the $65\text{-}70^\circ$ NE dipping primary fault. The southern fault was excavated in 3-D to carry piercing points into and across the fault. Four channel margins were isolated on the southern side of the fault whereas north of the fault, a single system of nested feeder channels was located. The stratigraphically highest channel, dated by AMS 14-C on charcoal at $10,650\pm 240$ BP, is right-laterally offset a minimum of 9.1 m. The next two channels both dated at about 14 ka, are offset a minimum of 16.3 m. The deepest channel deposit for which a lateral displacement was determined has a preferred 14-C age of $17,700\pm 250$ BP, and is displaced 25.5 m from the feeder channel system. These offset channels yield a minimum dextral slip rate of 0.9-1.4 mm/yr for the southwestern strand. A minimum of 5 discrete paleoseismic events are interpreted from increasing strata displacements and erosional fault truncations within the 10-20 ka stratigraphic record. Based on the similarity in geomorphic expression across both faults, a minimum slip rate of 2-3 mm/yr, with a maximum recurrence interval of 2000 years, is reasonable for the Whittier fault in the southeastern Los Angeles basin.

BRINGING EARTHQUAKE RISK TO THE CALIFORNIA STATE LEGISLATURE

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On October 4-6, 1995 the Association of Engineering Geologists (AEG) will hold their Annual Meeting in Sacramento, across the street from the California State Legislature. The meeting will be based on the theme "Diversity in Engineering Geology", and there will be a concerted attempt to involve members of state government in the meeting to achieve technology (knowledge) transfer. The policy makers in Sacramento are the people who, if reached, can make a difference in hazard reduction. It is imperative that California's government be aware of the seismic hazards across the state, and also, perhaps more importantly, the efforts underway to investigate and mitigate them. A special AEG symposium "Earthquake Hazards and Hazard Mitigation in California" is an outreach attempt by SCEC to work with AEG to achieve this knowledge transfer. The symposium will be divided into two parts, southern and northern California, to present the seismic hazard issues. Each session will conclude with a panel discussion of the progress (and opportunities) of earthquake hazard mitigation. Thanks to the cooperation of SCEC researchers from southern California [T. Henyey, M. Legg, G. Huftile, L. Grant, S. Lindvall, J. Dolan], and a distinguished group from Northern California organized by G. Simpson [K. Clahan, K. Coppersmith, D. Schwartz, W. Lettis, J. Hengesh], it appears

that the message will be well delivered. But will it be heard? An announcement of the entire meeting was mailed by AEG. A full-page, color announcement specific to the earthquake symposium was mailed to every member of the Senate and Assembly, and to every newspaper with bureaus in Sacramento. A follow-up reminder will be mailed two weeks before the meeting. After the meeting, a mini-proceedings pamphlet will be sent to the legislators to once again remind them of the prevalence of earthquake hazards in California, and the importance of knowledge-based mitigation legislation.

California Aseismic Deformation Field and Earthquake Slips from Geodetic Observations

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The horizontal aseismic deformation field and earthquake slip throughout California have been calculated from recent geodetic observations. We divided California into a number of blocks bounded by fault segments. We assumed that the strain rate is independent of time between major earthquakes. The effective motion on the ground is then a combination of rigid block translation, rotation, and elastic deformation generated by the dislocations on the fault patches. We used VLBI data spanning 1978-1992, trilateration data spanning 1970-1991 and GPS data spanning 1986-1994. Bayesian inversion theory was used to estimate the block motions and fault slips.

The model fits the data well, indicating that GPS data are compatible with VLBI and traditional trilateration data. The deformation across the San Andreas Fault agrees with geological and tectonic results. Strong rotations up to 5 degrees per million years were found in central and Western Transverse Ranges. The maximum 34 ± 2 mm/yr fault slip was found on the San Andreas fault, while the total motion across California is about 41 ± 2 mm/yr.

We derived the aseismic stress rate based on the model, and discuss the change of stress status along with the occurrence of major earthquakes in the pass.

Paleoseismicity of the North Branch of the Newport-Inglewood Fault in Huntington Beach, California

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Analysis of data from 72 cone penetrometer tests (CPT's), spaced 7.5 to 30 m apart, and 9 borings indicate that a splay of the North Branch of the Newport-Inglewood fault (NBNIF) displaces a 20 meter thick flat-lying section of Holocene sediments. The splay fault is located at a right-stepover of the NBNIF and has a normal component of motion. The CPT and boring data were analyzed and correlated to map the subsurface stratigraphy at a resolution of approximately 30 cm. Fifteen samples from the borings were radiocarbon dated. The basal unit, dated 11.7 ± 0.7 ka (2σ), is vertically displaced approximately 2.4 meters, yielding an apparent vertical slip rate across the splay fault of approximately 0.2 mm/year. Increased vertical displacement of sediment layers with depth indicate that multiple surface ruptures have occurred during the Holocene. Correlation of

apparent offsets at several fault locations suggests 5 recognizable paleoseismic events. The oldest event occurred shortly after approximately 11.0 - 12.3 ka. Two more events occurred prior to and shortly after deposition of a 7.7 - 8.0 ka (2σ) sample. Two additional recognized events are younger than 7.7 - 8.0 ka (2σ). Based on a tentative correlation of a radiocarbon date from elsewhere at the site and estimated sedimentation rates, it appears that the two most recent recognizable events occurred between 7.7 - 8.0 and 5.0 - 4.4 ka (2σ). Events younger than 4.4 - 5.0 ka may be present in the subsurface stratigraphy but cannot be recognized with the existing data. If the oldest event occurred shortly after deposition of the basal unit, then the average Holocene recurrence interval for ruptures on the NBNIF is ≤ 2.5 ka, and the average early to middle Holocene recurrence interval is ≥ 2.3 ka.

CRUSTAL STRUCTURE NEAR THE SAN GABRIEL MOUNTAINS FROM LARSE LINE 1

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As part of the 1994 Los Angeles Region Seismic Experiment (LARSE) survey, a dense reflection/refraction profile was conducted along a line extending northeastward from Seal Beach across the Los Angeles Basin and over the Transverse Ranges (San Gabriel Mountains) in Southern California. The survey consisted of 622 receivers (1-3 component), spaced at 100 m intervals under the mountains. This array recorded 64 explosions spaced at approximately 1000 m intervals along the line, producing a database of ~37,500 traces.

This portion of LARSE had three main objectives: 1) to obtain an image of the mid-crustal detachment zones beneath the Transverse Ranges; 2) to image the steeply dipping thrust fault systems along the front range of the San Gabriel Mountains; and 3) to image older low-angle thrust faults, e.g. the Vincent Thrust. Preliminary results obtained from analyses of data along Larse Line 1 show evidence for dipping faults on the south side of the San Gabriel Mountains, and sub-horizontal reflectors at 6.5-7 seconds, and 11-12 seconds. At this time no evidence for high angle faults on the north side of the range or of the Vincent Thrust has been seen.

WWW ACCESS to EARTHQUAKE RELATED INFORMATION FROM the SCEC DATA CENTER

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As a result of increasing accessibility to the Internet, interest in obtaining information about earthquakes in real time has expanded to a diverse group of users including researchers, emergency response groups, industry, public education, government agencies, the media and the general public. Much of this activity has been focused on accessing earthquake related information via the World Wide Web (WWW). Traditionally, the SCEC-DC has been providing researchers access to the large volumes of archived earthquake data via individual research accounts, as well as providing "near real-time" access to information shortly after an event.

Due to the increased interest in earthquake activity by users outside of the research community, the DC has been developing the WWW interface to provide more general

information about the SCEC-DC, earthquakes and activities of the SCEC. Users of the SCEC-DC WWW interface can access seismicity catalogs, "real-time" earthquake locations and maps, and weekly earthquake reports. Work in progress includes a LARSE home page, an "Earthquakes in Southern California" page, and a "Commonly Asked Questions about Earthquakes" page.

Patterns of Stress Drop in the 1994 Northridge Aftershock Sequence

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The aftershock sequence following the January 17, 1994, M_w 6.7 Northridge earthquake provides an opportunity to study the state of stress of the San Fernando Valley in more detail than possible with a regional inversion. We look for trends in static stress drop with location, depth, focal mechanism and orientation for several hundred M_l 2.5 to 4.0 aftershocks in order to constrain the local stress field.

For a simple faulting model, the static stress drop of an event is $7M_0/16r^3$, with r , the estimated radius of the rupture, proportional to the rupture duration. We use digital broadband velocity seismograms recorded at TERRAScope stations and at SCEC temporary stations to estimate the rupture duration of an event from the width of the initial P-wave pulse.

Static stress drops obtained range from less than 0.1 bar to around 50 bars. Preliminary analysis indicates possible increasing static stress drop with depth. Many of the highest stress drops obtained are from thrust events, although strike-slip and normal events also appear to have high stress drops in some areas.

EFFECTS OF THE M8 FT. TEJON, CA EARTHQUAKE OF 1857 AND THE M7.7 KERN COUNTY, CA EARTHQUAKE OF 1952 ON SUBSEQUENT EARTHQUAKES IN SOUTHERN CALIFORNIA

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The M8 Ft. Tejon earthquake ruptured the San Andreas fault from near Parkfield to near Wrightwood, California. We determined the static stress changes generated by dislocation models of the earthquake at the sites of subsequent $M > 5.5$ southern California earthquakes. The 1857 earthquake increased the stress on many faults SE of the rupture, such as those of the San Jacinto fault zone, and relaxed many faults in the Transverse Ranges. The stress "relaxation" shadow caused by the 1857 earthquake was gradually eroded by long-term tectonic loading. Beginning in 1907, a mix of strike-slip and reverse earthquakes resumed in southern California, as some faults started to emerge from the shadow.

In 1952 southern California was hit with its next largest event, the M7.7 Kern County earthquake. A relaxation shadow accompanying the 1952 earthquake delayed $M > 5.5$ earthquakes in the Transverse Ranges for at least 35 years and was overcome by long-term tectonic loading in parts of the Los Angeles basin starting in 1987. In 1987 events such as the Whittier Narrows earthquake began to occur on formerly relaxed faults, and seismicity in the LA basin started its return to "normal" background rates. We suggest that the recent increase in $M \sim 6$ events in the LA basin reflects the gradual return to

background levels associated with tectonic reloading of faults previously relaxed by the 1857 and 1952 earthquakes.

Refined Three-Dimensional Velocity Model for the Central Transverse Ranges and the Los Angeles Basin

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We use earthquake arrival time data to invert for the VP and the VP/VS structure beneath the central Transverse Ranges and the Los Angeles basin. Explosion data, recorded by the SCSN, from quarry blasts and the LARSE experiment are also included in the inversion. The study area includes the Los Angeles basin, the central Transverse Ranges and the eastern Ventura basin. At shallow depth the graded inversion VP velocity model images the shape of the Los Angeles and eastern Ventura basins. The Los Angeles basin extends to a depth of 8 km and is bracketed by the Newport-Inglewood fault on the west and by the Whittier fault on the east. The east Ventura basin, elongated in an east-west direction narrows with depth to 12 km. The north edge of the Peninsular Ranges, the Santa Monica, and the San Gabriel mountains, form high velocity ridges. In detail the Santa Monica mountains form two high velocity ridges, in the depth range from 0 to 10 km, separated by a zone of intermediate velocities, located north and west of the northern terminus of the Newport-Inglewood fault. Similarly, the velocity structure of the San Gabriel mountains exhibits complex geometrical relationships with the nearby lower velocity basins.

A Kinematic Model of the Southern Walker Lane Belt

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We have developed a kinematic model to better understand Walker Lane Belt deformation. We use the finite element code GAFA to simulate the region as a two-dimensional elastic continuum broken by faults. Fault locations are based on the Jennings (1992) fault map of California and locally refined based on more detailed mapping studies. Deformation is driven by prescribed velocities on the model boundaries and, where data are sufficient, by prescribed fault slip rates. Other faults are allowed to slip freely in directions consistent with the fault type and orientation. Based on geodetic data, the Sierra Nevada block (on the western boundary of the model) is modeled as a rigid body rotating around a pole located west of the modeled area. We test various Great Basin extension rates to define the model's eastern boundary.

We find that extension in the southern Great Basin is much slower than in the northern Great Basin (i.e. at Ely, NV). When we assume that the Sierra Nevada block rotates as indicated by Dixon et al. (1995), the maximum allowable extension across the southern Great Basin is about 2 mm/yr (compared with 5 mm/yr measured at Ely). When the Argus and Gordon (1991) Sierra Nevada rotation pole is assumed, even less extension in the southern Great Basin is permitted. We also observe that right-lateral faulting is required in the Owens Valley south of the Owens Valley Fault.

GPS Time Series in Southern California

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The Southern California Integrated GPS Network (SCIGN), a joint effort of NASA, NSF, and the USGS under the umbrella of SCEC, presently consists of 30+ GPS stations in Southern California. This network is projected to grow to 200+ stations in 2-3 years.

The main goal of the SCIGN is to provide data which will allow us to refine the seismic hazard models by identifying active structures within the greater Los Angeles area. This will be accomplished through production of particle velocities with a spacing of 2-15 km and a resolution of +/- 1 mm/year. Active structures can then be targeted for more detailed geological and geophysical investigations.

Point positions for 30-40 sites in Southern California are computed daily at JPL. A typical site like the one at UCLA has absolute daily coordinate repeatabilities of 5 mm N, 7 mm E, and 10 mm V without ambiguity resolution. Repeatability for a typical baseline is at the level of about 2 mm. A global network of 34 sites provides precise orbits, satellite clocks, and earth orientation parameters. Precise point positions for the entire network take about 1-2 CPU hours on an HP735 workstation. Time series are available via internet at <http://sideshow.jpl.nasa.gov/mbh/point.html>. Precise, cost effective GPS measurements of crustal deformation in Southern California will lead to a better understanding of seismic hazard models in the Los Angeles basin.

The Origin of Slip Partitioning at Zones of Oblique Convergence: Applications to the San Andreas System in California

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In most plate boundary zones involving oblique convergence there is a partitioning of strains such that the motion parallel to the plate boundary zone is taken up by strike-slip faults and the component of velocity perpendicular to the plate boundary is taken up on thrust structures [Fitch, 1972, Jarrard, 1986]. Where relative motion is oblique, the slip vectors at trenches do not represent the true relative plate motion direction and therefore cannot be used in plate motion calculations [DeMets et al., 1990]. In this paper I demonstrate that the partitioning of slip at zones of oblique convergence is a simple kinematic requirement. Within the plate tectonic paradigm, plates are rigid to some depth and move over the top of a fluid-like asthenosphere. The plate boundary zone that accommodates the oblique motion is often diffuse. If the relative motion of the base of the rigid portion of the lithosphere can be described by the same angular velocity about the Euler pole as the top of the lithosphere (i.e. the horizontal velocity is the same at all depth points within the rigid lithosphere at a prescribed distance from the Euler pole), then this kinematic constraint requires a partitioning of slip within the zone of diffuse deformation that accommodates the relative motion. Satisfying the kinematic boundary condition across the zone of oblique convergence, while minimizing the second invariant of the strain rate tensor, predicts that the slip vector in the thrust zone will always lie between the direction normal to the plate boundary zone and the direction of relative plate motion. The minimum of the second invariant of the strain rate tensor is equivalent to the minimum in work rate for a straining viscous medium. The simple model predicts the slip vector direction on the thrust fault at the plate boundary zone when the dip of the thrust and the relative plate

motion vector are known. Using this model the predicted rake values for the Coalinga, Loma Prieta, and Northridge earthquakes are 111, 137.5, and 107 degrees, respectively, which is in good agreement with observation. That the kinematic constraint, along with the requirement that the second invariant of the strain rate tensor be a minimum, provides a good match to observation, argues that the brittle deformation in the top portion of the lithosphere may be linked or coupled to the flow of the upper mantle lithosphere within the zone of deformation.

Seismic Images of the North Channel Fault near Santa Barbara, CA

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The North Channel fault is the western continuation of the San Cayetano-Red Mountain-Pitas Point fault trend that forms the northern edge of the rapidly deforming Ventura Basin. The Pitas Point - North Channel fault was responsible for the 1978 Santa Barbara earthquake and aftershock sequence (Lee et al., 1979). The fault is well imaged by seismic reflection data from the city of Santa Barbara to west of Goleta. In this area, a high amplitude fault plane reflector is imaged by both 2D and 3D seismic surveys with a wide range of acquisition parameters. The seismic data indicate that the North Channel fault is a blind thrust that dips 20-40 degrees to the north. The fault tip occurs in the Pleistocene Pico Formation at a depth of 1.5 km subsea (1.5 seconds two-way time) and the fault plane steepens near its termination. A change in structural dip occurs at the fault tip, which corresponds with one of the axial surfaces mapped by John Suppe (pers. comm., 10/7/94). The fault plane is imaged to a depth of 3.7 km (2.5 seconds two-way time), at which depth there is significant offset of Miocene reflectors. A deeper thrust is also imaged on some seismic lines.

In map view the fault plane bifurcates at two places: 119° 45' W and 119° 56' W. These locations correspond to the longitudes at which en echelon offsets occur in the trend of the hanging wall anticline above the North Channel fault. It is therefore concluded that the North Channel fault is comprised of fault segments about 15 km in length. This conclusion is consistent with the observation that the aftershock sequence for the 1978 Santa Barbara earthquake extend for a distance of 12 km along a different segment of the North Channel fault (119° 41' W to 119° 49.8') with a hypocenter at 13 km.

Deformation Rates Across the Placerita (Northridge $M_w=6.7$ Aftershock Zone) and Hopper Canyon Segments of the Western Transverse Ranges Deformation Belt

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Aftershocks of the 1994 Northridge ($M_w=6.7$) earthquake provide insights into the geometry of the seismic source faults in the San Fernando Valley and the east Ventura basin and allow the calculation of deformation rates for the region. The Northridge thrust and Santa Susana faults dip in opposite directions, with the Northridge thrust entirely beneath the Santa Susana fault. These opposing reverse faults interact, resulting in a folded active Santa Susana fault and uplift in the footwall block of that reverse fault.

Two balanced cross sections suggest thick-skinned deformation of the western Transverse Ranges. The western section, across the Modelo lobe segment of the north-dipping San Cayetano fault and the easternmost surface trace of the south-dipping Oak Ridge fault, is west of any aftershocks of the Northridge earthquake and has been termed

the Hopper Canyon segment of the deformation belt. Structural modeling predicts a dip of 46° S on the Oak Ridge fault at seismogenic depths. Horizontal shortening rates are calculated by adding the products of the dip-slip displacements and the cosines of the dips of both faults. The eastern cross section shows the Northridge main shock, with a 45° south-dipping nodal plane at a depth of 18 km. Aftershocks reach a depth of 20 km depth. In a thin-skinned paradigm, a hinge should occur at the surface near the Santa Monica Mountains due to rocks moving from a décollement at the brittle-plastic transition and changing dip as they move up the ramp. No hinge of that magnitude occurs there. Calculation of horizontal shortening rates across this part of the western Transverse Ranges must take into account the displacement on both the Northridge thrust (eastern extension of the Oak Ridge fault) and the Santa Susana fault (Placerita segment).

Horizontal shortening rates are 8.2 ± 2.4 mm/y across the Modelo lobe segment of the San Cayetano fault and the Oak Ridge fault, and 5.7 ± 2.5 mm/y across the Northridge thrust and the Santa Susana fault. These rates are consistent with those based on tectonic geodesy using GPS. Dip-slip displacement rates on the faults are 1.7 mm/y for the Northridge thrust since 2.3 Ma, 3.8 ± 0.4 mm/y for the Oak Ridge fault since 500 ka, $5.9^{+3.9}_{-3.8}$ mm/y for the Santa Susana fault since 600-2300 ka, and 7.4 ± 3.0 mm/y for the Modelo lobe segment of the San Cayetano fault since 500 ka. This indicates that the slip rates on the north-dipping faults, the eastern San Cayetano and the Santa Susana faults are comparable, but the slip rate on the south dipping faults decreases eastward; the slip rate on the Oak Ridge fault in the Ventura basin is more than double that of the Northridge thrust.

Tectonics of the Greater Los Angeles Region: Implications for the Lower Crust and Upper Mantle

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Pacific-North America transform accommodation is distributed broadly across southern California and its borderland. This deformation is driven by "plate forces" created in other parts of the world. Faulting is dominated by the San Andreas fault, which takes a large left step (Big Bend) through the Transverse Ranges region. Crustal flow and tectonics associated with the Big Bend are distinctly non-transform in nature: southern California crust acquires an anomalously westerly velocity where it flows around the Big Bend, and thrusting is common where southern California crust "funnels" into the relatively narrow central California Coast Ranges. This activity is attributed to the action of convergence-driving forces created locally by mantle lithosphere converging and sinking beneath the Transverse Ranges. Crustal convergence driven by these forces would occur at greater rates across the width of the Big Bend were it not for the divergence-driving forces generated by the Transverse Ranges topography. Instead, crust such as the San Gabriel block avoids convergence by "escaping" to the west, accommodated in part by left-lateral faulting along the southern margin of the Transverse Ranges; large amounts of thrusting are thereby transferred to the western Transverse Ranges, where thrusting requires less work because topography is lower.

Lower crustal decoupling must exist between the NW-moving mantle lithosphere and the more westerly moving crustal blocks, and as the crustal blocks move west of the Big Bend they slide off of their mantle lithosphere. The mantle lithosphere descending beneath the Transverse Ranges may be abandoned Farallon slab: if the Pelona-like schists represent a regional subduction complex emplaced beneath North America crust by Laramide-aged subduction, then the lithosphere would be abandoned slab both because the observed lithospheric thickness is too great to be post-subduction thermal boundary layer,

and because the low to inverted gradient in the Pelona-like schists implies no asthenospheric inflow as would occur behind the withdrawing slab. Hence, we expect to find the relic slab features of upper mantle anisotropy (fast E-W, in the Farallon spreading direction) and a basalt layer (currently near the base of the seismic crust).

Scaling Law of Aftershock Spectra of Landers-Big Bear and Northridge Earthquakes

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The subject of this study is the relationship between fault zone structure and the seismic spectra generated by earthquakes on the fault. From a rupture mechanics point of view, a fault zone governed by a friction law with given parameters (such as the breakdown zone size and the magnitude of critical weakening slip) should result in a scaling law of seismic spectrum which deviates from the self-similarity. On the other hand, an observed seismic spectrum is a function of source, path, and receiver site. In order to eliminate the path and site effects, we use spectral ratio between two earthquakes sharing a common path and site to estimate the source parameters for earthquakes with seismic moments ranging from 10^{27} to 10^{17} dyne-cm.

First, we selected 10 master-events for which seismic moments have been determined. The aftershock pair is selected by two rules: (1) the hypocentral distance between the selected aftershocks and one of the master-events must be less than 2 km; (2) these two events share similar focal mechanism. About 100 aftershocks for Landers-Big Bear and 80 for Northridge earthquakes are selected. Seismograms recorded at TERRAScope and portable stations for the selected aftershock pairs are used to obtain the observed spectrum.

In order to overcome a trade-off problem between the variance of the estimate and the spectral leakage of energy from outside the taper band caused by using a single taper, we use the multitaper analysis to obtain the observed spectrum for each earthquake. Then the spectral ratio for each pair is calculated at each station. The corner frequencies of the pair and the seismic moment relative to the master-event were determined for earthquakes with moments ranging from 10^{27} to 10^{17} dyne-cm by applying a non-linear least-squares fitting to S-wave spectral ratios.

We found a strong tendency for corner frequency to keep a constant when seismic moment between 10^{21} to 10^{18} dyne-cm. By comparing with the borehole data, we believe that this is, most likely, not due to inadequate path and/or site correction.

California Earthquake Catalog from 1769 to 1994

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This catalog compiles earthquakes in California within the latitudes of 114°W to 128°W and longitudes of 31°N to 42°N between the years of 1769 and 1994. Earthquakes with any magnitude or moment value greater than or equal to 5.5 are included. The catalog is based on the California earthquake catalog published by Ellsworth (1989), the electronic

and paper monthly publications of the "Preliminary Determination of Epicenters" (PDE), and the electronic Harvard catalog. Magnitude scales examined include: local magnitude (M_l), surface-wave magnitude (M_s), seismic intensity (M_i), seismic moment (M_w), a summary magnitude by Ellsworth (M_{sum}), and a summary magnitude (M_{ucla}) created by the Southern California Earthquake Center (SCEC) at the University of California, Los Angeles (UCLA).

Dense GPS Profiles: Can They Distinguish Between LA Fault Models?

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The overall tectonic framework of the Los Angeles Basin - contraction perpendicular to the axis of the basin combined with NW-SE shearing - is relatively well understood, and estimates of the rate of contraction (about 9 mm/yr) have been known for some time. However, on a more detailed level, that of individual faults, it is not known which of the myriad structures in the basin are currently active and which are not. (The Northridge earthquake in January, 1994, serves as the most recent example of a previously unidentified fault which ruptured and caused significant damage.) Knowing which Basin thrust faults are actively accumulating strain energy is of fundamental importance to earthquake hazard evaluation in southern California.

Plans are underway to greatly expand the number of continuously operating GPS receivers in the LA Basin in order to begin to determine the partitioning of crustal deformation. One element of this plan is a dense linear profile of sites across the basin. The hope is that such a profile of measurements will be able to distinguish which of the faults it crosses are active and also whether previously unknown structures exist and where they are located.

I have performed simulations of such profile networks in order to understand their ability, as a function of measurement accuracy, to distinguish between simple models of faulting. I have used three models: 1) a single active thrust fault in the center of the Basin which accommodates all of the contraction, 2) two active thrust faults, each of which accommodates half of the total contraction, and 3) three equally active thrust faults. A network consisting of 40 stations evenly distributed within a 60-km-long profile (approximately the maximum width of the Basin) can discriminate between a one-fault model and a two-fault model only if the site velocities are known to within ± 0.6 mm/yr assuming the overall deformation across the Basin is 9 mm/yr. (More realistically I assume that half of the total sites achieve this level of uncertainty [0.6 mm/yr], one quarter of the site velocities are 50% less certain [0.9 mm/yr], and the remainder are 100% less certain [1.2 mm/yr].) This same network can discriminate between a two-fault model and a three-fault model only if the velocity uncertainty is less than about 0.2 mm/yr. Daily GPS measurements made over a period of five years have the potential to produce velocity uncertainties below 1 mm/yr, but only under the very favorable circumstances of highly accurate daily GPS positioning estimates (less than ± 2 mm) and very stable monuments (less than $2 \text{ mm}/\sqrt{\text{yr}}$ assuming a random-walk model for monument instability). It is very unlikely that velocity uncertainties as low as 0.2 mm/yr can be achieved during a five year experiment.

EARTHQUAKE SIZE DISTRIBUTION AND EARTHQUAKE INSURANCE

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I determine the parameter values for the seismic moment-frequency relation using the Flinn-Engdahl regionalization of global seismicity and the Harvard CMT data. The earthquake size distribution is approximated by the gamma law which is a version of the Gutenberg-Richter (Pareto) distribution with an exponential taper at the maximum moment. There is no statistically significant variation of the β -value (the analog of the b -value) for all seismic regions except for the mid-ocean ridge systems. For the latter regions $\beta = 0.93 \pm 0.05$, whereas for all other zones $\beta = 0.64 \pm 0.01$. The maximum moment can be statistically evaluated only for subduction zones treated as a whole, $M_{max} = 10^{28} - 10^{29}$ dyne cm, the same as the worldwide value. For other regions, as well as for single subduction zones, M_{max} is determined by comparing the number of events in each zone with the seismic moment rate calculated on the basis of the *NUVEL-1* model of plate motion. No statistically significant variation is found in M_{max} for subduction and continental collision zones, the maximum moment for these regions is the same as the global value. These results have important implications for seismic risk evaluation and for the development of physical theory for earthquake generation. Since both parameters β and M_{max} do not change in a statistically significant way over continental areas and tectonic plate boundaries, very large earthquakes are possible in practically any urbanized areas. I present evidence that the statistical distribution of losses due to large earthquakes has a power-law (Pareto) tail with an exponent value less than 1.0. If this statement is true, the earthquake average loss is controlled by the largest earthquakes. Since the distribution of earthquake size at the maximum, as well as the distribution of maximum losses are not well known, it implies that insurance premiums can be determined only with significant uncertainty. I simulate the insurance ruin potential for three earthquake loss distributions: exponential, Pareto with exponent 3/2 and with exponent 2/3. The possibility of catastrophic losses due to great earthquakes suggests that the probabilities of the ruin of insurance companies are unacceptably high, unless the risk reserves are equal to or exceed the maximum possible loss.

Inversion Tectonics And The Oak Ridge Fault And Fold System, Eastern Santa Barbara Channel, California

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Seismic reflection and well data are used to define the geometry of faulting and folding in the eastern Santa Barbara Channel. These data show the Oak Ridge trend consists of shallow to tightly folded Quaternary to Oligocene strata above a steeply south-dipping reverse-separation fault with up to 2.6 km of separation. Steep to overturned strata, repeated, and offset sections, and stratigraphic changes revealed in wells, are not accurately imaged by multi-channel seismic data. The Oak Ridge fault is inferred to be an active fault based on high-resolution seismic data which show offsets of a near sea-bottom unconformity, sea floor scarps, and recent earthquake hypocenters that align along a south-dipping structure. Stratigraphic changes across the fault include unconformities to the south of the fault which imply at least two major periods of uplift followed by subsidence and deposition. These unconformities are not observed north of the fault.

The geometry of the onshore and offshore segments of the Oak Ridge fault are consistent with a model of tectonic inversion in which the fault originated as a late Oligocene-Miocene normal fault that has been reactivated with strike-slip and reverse displacement. The observed geometry is difficult to reconcile with fault-bend-fold models which infer only moderate to shallow dipping fold limbs above low-angle north-dipping fault ramps, and constant formation thicknesses.

The Passive Phase of the Los Angeles Region Seismic Experiment (LARSE)

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The Los Angeles Region Seismic Experiment (LARSE) consisted of two phases: passive (fall, 1993) and active (fall, 1994). During the passive phase, approximately 88 stations were deployed in a 175-km-long linear array across the Los Angeles basin, San Gabriel Mountains, and Mojave Desert northeast of Los Angeles by scientists from the U.S.G.S., UCLA, Caltech, and USC. During the four weeks of continuous recording, over 160 teleseismic and over 400 local events were recorded at each site. The goal of this experiment was to collect waveform data from local and distant earthquakes to obtain three-dimensional images of lower crust and upper mantle structural features in Southern California, particularly under the San Gabriel Mountains and San Andreas fault.

P-wave travel times were determined from station records of 17 teleseisms and corrected for topography and one-dimensional Earth model. Within each back-azimuth range, the resulting travel-time residual curves display consistent patterns with relatively low residuals at the southern San Gabriel Mountain foothills and relatively large residuals across most of the San Gabriel Mountains, including the San Andreas fault. The most drastic differences in residuals, occurring for raypaths from the northwest, are about one second. The travel-time residual curves display 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 suggest that a sharp change in shallow velocities is required between the Los Angeles basin and the San Gabriel Mountains over a horizontal distance of less than 10 km. A model of Southern California crust which consists of oceanic crust under the Los Angeles basin to the southwest of the array next to continental crust under the San Gabriel Mountains would explain the residual patterns.

Activity Flipping Between Parallel Faults Under Anti-Plane Strain

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We wish to understand some of the complex interactions in multiple fault systems. Here we simulate two parallel faults in an elastic bond model driven under anti-plane strain. For simulations of several hundred thousand events, comparable to very long geologic times, it is found one fault will be active with the other almost completely silent for periods of time. Then activity quickly flips to the silent fault while the other becomes quiet. During

active periods a fault displays stationary behavior similar to that of a single fault system and then enters a period of quiescence. As the fault separation decreases the number of shorter quiescent time intervals increases. The distribution of quiescent time intervals is found to follow a power law with exponent a function of fault separation reaching a maximum of 0.8 for closest separation. This initial inquiry illustrates the possibility of fault activity moving from fault to fault over long time scales. It is also important to note that in looking at the activity of only one of these faults over a long enough period one might conclude the fault history is non-stationary.

Prototype of Paleoseismic and Active Fault Digital Database Interface using ArcView 2

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The SCEC GIS Research Facility has recently completed construction of two new digital databases. The first was the updating of the Alquist-Priolo fault database with new Landers data, and revision of all Alquist-Priolo faults within San Bernardino county. We have given the designation of Alquist-Priolo Fault Database 2.0.0 (APFD 2.0.0) to this new product. The old version will now be known by the designation, Alquist-Priolo Fault Database 1.0 (APFD 1.0). In addition, new segmentation was applied to the APFD 2.0.0 using information in Wesnousky (1986) and Peterson and Wesnousky (1993). This was done to facilitate use of the APFD 2.0.0 with the second recently completed database, the Peterson/Wesnousky Paleoseismic Information Database (PID). This database puts into digital form the complete table of paleoseismic sites compiled by Peterson and Wesnousky (1993) - providing paleoseismic information at discrete points, that can be flexibly associated with segmentation datasets.

With the advent of more powerful desktop GIS software, most notably ArcView 2.0 from ESRI, comes the ability to design a useful and user-friendly interface to aid users in seismic hazard analysis. The SCEC GIS Research Facility has started to develop a database framework in ArcView 2, so that more users will have access to databases and algorithms developed at the GIS Facility. The prototype of this interface presented here is built on the basic environment provided by ArcView 2 "out-of-the-box". Further enhancement of the interface is possible by use of the Avenue programming language that ArcView 2 is built on. Avenue programming enhancement has not yet been implemented, because licensing for Avenue has only recently been acquired. Even without Avenue enhancement, ArcView 2 provides a powerful interface for querying and visualizing Arc/Info databases. Users will be able to view information on paleoseismicity and active faults, along with many other layers such as, seismicity, cultural information, geology, etc.

This demonstration of the prototype interface will exhibit some of ArcView's query and visualization power. Users will be able to browse through paleoseismic and fault databases either graphically or textually via a spreadsheet. They will be able to locate features by use of attributes in other databases.

FAULT-ZONE TRAPPED WAVES EXCITED BY EXPLOSIONS AT THE LOCKED, CREEPING AND RUPTURED FAULT ZONES, CALIFORNIA

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Recently, we used explosions to excite seismic guided modes within the fault zones at which we have observed fault-zone trapped waves from earthquakes. The explosions

were detonated at the Landers fault in Mojave desert by USC/SCEC/USGS, at the San Andreas fault near Parkfield by the USGS/USC/DUKE and at Cienega Valley, the northern Gabilan Range by the USGS/UW-Madison/RPI. We deployed dense seismic arrays across the fault traces to record fault-zone trapped waves. The trapped wave data from explosions further confirm the existence of a low-velocity fault zone which extends along the surface breaks and bottoms at the lower crust, but is broader and with slower materials near the surface than at depth. The Landers fault zone that ruptured in the M7.4 Landers earthquake of 1992 is broader and has lower velocities than either the San Andreas Parkfield segment, which is a transition between the creeping and locked parts of the fault zone or the creeping segment at Gabilan Range. However, the Parkfield segment, which endured the recurrent M~6 earthquakes is broader and has lower velocities than the Gabilan segment on which only M5 or smaller events occurred. This suggests that the degree of rock damage within the fault zone is a function of dynamic rupture during the earthquake. Our results also elucidate that we can use trapped waves excited by explosions to study the fine structure of the aseismic faults.

The Fine Structure of The San Jacinto Fault Near Anza, California, Inferred by Fault-Zone Trapped Waves

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Recently, we deployed two 8-element tight seismic arrays across the San Jacinto/Casa Loma fault (SJF/CLF) and Hot Spring fault (HSF) ~15 km northwest of the Anza seismic gap to record fault-zone trapped waves for the study of fault branching. The coda-normalized amplitudes of trapped waves at the SJF/CLF have the maximum peak at 4 Hz, which decays sharply with distance from the fault trace. Trapped waves from events occurring near the epicenters of the 1899 M7.0 and 1918 M6.8 earthquakes ~40 km northwest of Anza appear only at the array located at SJF/CLF but not at HSF, inferring that the major fault-plane waveguide exists along the SJF/CLF rather than HSF. The hypocentral projection of events for which we observed trapped waves suggests that the fault-plane of SJF/CLF dips northeastward at 75° , but disconnects to the HSF which may be a shallow and inactive fault branch. We also found that trapped waves recorded at the SJF in the Anza gap have higher frequencies (6-8 Hz) than those registered at the SJF/CLF and the Coyote Creek Fault (CCF) which was ruptured in the M6.8 Borrego Mountain earthquake of 1968. This infers that the fault zone at the seismic gap is narrower than on other segments of the SJF around Anza. Finite-difference simulations of trapped waves result in the width of the fault-zone waveguide to be 100-150 m at the SJF/CLF and CCF segments, but is narrower than 100 m at the Anza seismic slip gap. The shear velocity within the fault zone is reduced about 30%.

Expected Geodetic Deformation from Blind Thrust Faults

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Recent study has focused on the potential benefits of continuously monitoring crustal deformation in the Los Angeles Basin of southern California, using a dense array of a few hundred Global Positioning System (GPS) geodetic instruments. Among the anticipated results of such a geodetic program would be improved knowledge of the spatial scales of the regional strain field. This knowledge would lead to improved understanding of the geologic structures governing deformation and earthquakes in the basin. This work is aimed at assessing the influence of crustal structures on the expected deformation signatures that would be observed with a dense GPS array. Viscoelastic finite element simulations showing surface deformation profiles are presented for a suite of structural models and earthquake recurrence intervals.

Use of Emerging Technologies for the Digital, Real-Time, Earthquake Monitoring System in Southern California

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Caltech/USGS is developing a prototype, real-time system that at present includes 24 digital stations, a combination of very broad band sensors and dataloggers (TERRAscope) and sensors, and digital strong motion instruments (AMOES). Data from these instruments are telemetered in digital format via Pacific Bell Frame Relay Service (CalREN) and the USNSN/VSAT system. The telemetered data are recorded and processed on a workstation at the central site. This data processing system continuously monitors the seismic activity in the network to produce a variety of seismic information, such as earthquake locations, magnitudes, and acceleration values for each site. Much of the software runs on real-time data streams producing information about the events while they are still occurring. Access to the network data is provided to researchers over the laboratory's local area networks in either a real time mode, or via a batch oriented data request. The parametric data produced by the system is disseminated several ways, including paging system (CUBE), email, dial-in access, network access, and the world-wide web. The data recorded by the system is also archived to tape for long term storage at the Southern California Earthquake Center, Data Center (SCEC/DC).

THREE DIMENSIONAL SIMULATION OF GROUND MOTION IN SAN FERNANDO VALLEY

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We have developed a scalable, workstation-based procedure for 3D simulations of earthquake ground motion in the presence of very large seismic velocity contrasts. The method accommodates models with a large range of seismic velocity by using a form of adaptive gridding (recursive grid refinement). We have also developed a high resolution 3D geologic model for the L.A. region for use in the simulations, and this model has been distributed to other investigators engaged in ground motion prediction for the L. A. region.

We have completed 3 simulations of the Northridge mainshock to investigate the sensitivity of ground motion predictions to the rupture model. We have also completed simulations of 6 Northridge aftershocks, with the objective of investigating sensitivity of ground motion predictions to source location and mechanism. The simulations focus on low-frequency ground motion, with upper cutoff frequency of 0.4 Hz (one case had upper cutoff of 0.8 Hz). In all cases, maximum low-frequency horizontal velocity is correlated with depth to basement. In most cases, the predicted maxima are concentrated within the 10,000 ft. depth-to-basement contour. For a shallow aftershock outside the San Fernando Valley, the simulation also predicts high amplitudes along the nearest basin margin.

Probabilistic and Sensitivity Analysis of Ground Motion Parameters in Southern California

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One of the objectives of this study is to generalize the process of constructing regional seismicity models. The other objective is related to the fact that the information in the Phase II Report and the paper by Dolan et al. (1994) are being used by the engineering community in southern California for the probabilistic seismic hazard analysis (PSHA). Therefore, it is necessary to investigate the sensitivity of such PSHA to the uncertainties in different seismic parameters and data integration.

I have integrated the construction of the regional seismicity models into the PSHA. This enables us to manipulate different earthquake-related parameters and data integration scenarios very efficiently. A D-zone is added to the list of A, B, and C zones to allow different weighted integration of seismic, geologic, and geodetic data for moment budget calculation. The concept of the characteristic earthquake is extended from a single magnitude earthquake to earthquakes of different magnitudes with normal distribution. The relative amplitude of the density distribution for the set of characteristic earthquakes is taken as variable to allow constructing different seismicity models between two extremes of a purely Gutenberg-Richter and characteristic earthquake(s)-type models. Typical examples of the regional seismicity models based on the SCEC and Dolan et al. (1994) databases are constructed.

A modest sensitivity analysis for a single source zone in southern California may require more than ten thousand PSHA case studies. The problem becomes more complicated when integrating different scenarios from different sources that contribute to the PSHA at a site. In order to reduce the CPU time the analysis on the spatial distribution

of rupture areas is de-coupled from the analysis on the magnitude-rate distribution of earthquakes. Also the calculation of uncertainties on different parameters are grouped together to further simplify the problem. Nevertheless, the sensitivity analysis is tedious, costly, and time consuming process. The engineering community does not have the patience of doing such analysis except for very special projects. However, many important projects are designed based on the results of PSHA with marginal safety factors. Therefore, for safer and more reliable design procedure it is necessary to quantify the uncertainties on all seismic parameters, perform the sensitivity analysis on PSHA, and communicate the results to the engineering community.

Activities of the Portable Broadband Instrument Center

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The PBIC provided equipment to more than 12 projects over the past year, many with funding sources external to SCEC. The projects cover a wide range of scientific goals, including blast monitoring, network calibration and earthquake monitoring. Demand for the PBIC's 16 DASs continues to increase, along with scheduling conflicts. Much of the recent demand for equipment has been for projects involving upwards of 10 sites of equipment which is within reason for the current suite of instruments. The PBIC will increasingly utilize its recently created WWW page, now with a DAS timeline, to distribute equipment status information to Internet users. In the past year the PBIC has responded to over 200 email messages involving SCEC issues. The PBIC has attempted to automate the recovery and archival of all log files from SCEC project DASs. This allows the PBIC to gather more accurate statistical information regarding its equipment. Over the past year, projects using PBIC equipment have collected ≈ 4.5 Gb of data. These projects recorded ≈ 500 events that are associated with known events in the RTP catalog. An additional ≈ 1300 events are associated within the portable recorders themselves.

SLIP VARIABILITY ALONG THE 1992 LANDERS EARTHQUAKE RUPTURE: IMPLICATIONS FOR STUDIES OF PREHISTORIC RUPTURES

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Variations in surficial slip have been reported along previous strike-slip ruptures, but the closely spaced slip measurements that were made along the rupture of the 1992 Landers earthquake allow a much more detailed study of slip variability than was possible previously. We have analyzed slip variability using our own measurements along 5-km length of the Emerson fault, as well as the measurements made by other geologists along other portions of the rupture. We document variations in slip as large as 1-2 meters over distances ranging from 1-2 kilometers to a few tens of meters. These variations are only slightly smoothed when the slip on secondary fractures is added to the slip across the main fault trace(s).

The variability of slip along the ruptures associated with the Landers earthquake calls for caution in interpreting geomorphic offsets along prehistoric fault ruptures. McGill and Sieh's (1991) method of using histograms to distinguish the number of earthquakes

associated with particular offset features is not always valid, but may be useful in some cases, if a running average is subtracted from the offset measurements before the histogram is constructed. The slip gradients between offset measurements along the Landers rupture were large enough (up to 0.17) that it will only very rarely be possible to argue that offset features along a prehistoric rupture formed in different numbers of events due to the lack of a historical precedent for so large a slip gradient. Therefore, other methods must be developed to distinguish the number of earthquakes associated with offset geomorphic features along prehistoric fault ruptures.

Application of Evolutionary Programming to Earthquake Hypocenter Determination

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As models of seismic velocity in the Earth's crust are refined to accommodate larger and better data sets, they tend to become locally "rough" where they are best resolved, with nonplanar interfaces, and complex structures. This means that perturbation techniques which rely on differentiability of travel-times with respect to source coordinates are likely to fail, or to give erroneous results with little evidence that the answer is wrong. With even relatively simple three-dimensional structures involving dipping discontinuities, correct identification of seismic arrivals-or "phases"-can be problematic, and precise event locations elusive. We investigate the applicability of evolutionary programming (EP) to this problem and conclude that it yields satisfactory results, provided that no gross errors are present in the observations. Realistic applications to routine locations of earthquakes in a three-dimensional crustal model call for an effective ray tracing and travel time calculation strategy.

Worldwide Performance of a Seismicity-Based Intermediate-Term Prediction Algorithm: the M8 Algorithm, $M > 7.5$, 1985-94

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We construct the Receiver Operating Characteristic (ROC) curve for the M8 algorithm, based on worldwide seismicity ($M > 4.0$) between 1963 and 1995. 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 defined as the complete set of points at the surface of the Earth where the algorithm can actually be executed, for events with magnitude 7.5 and greater. "Time" is the period 1985-95, over which the algorithm has stabilized. As a decision rule to define the set of points where an alarm is in effect at any given time, we use the criterion that the likelihood that a Time of Increased Probability, or TIP, should exceed a preset threshold at that time and location. Our null hypothesis is that the algorithm performance is no better than a random sampling of space-time with a uniform probability density. The alternative (desired) is that the algorithm samples space time in a much more selective way. The null hypothesis allows us to construct a 95 confidence band, based on a hypergeometric distribution. If the ROC remains within this band, the null hypothesis cannot be rejected. Furthermore, for a "real-time" assessment, the procedure can be formulated in terms of a sequential test. Finally, the robustness of the

results with respect to the likelihood threshold used in the decision rule can be conveniently explored.

For each 6-month interval between 1985 and 1995, we executed M8 on past seismicity for a very large number of circles tiling the entire planet, for a total of nearly 107 runs. We found two decision rules for which M8 appears to perform marginally better than random. The first one selects approximately 15 percent of the total space time, with 8 successful predictions out of 25 events, and the second one selects about 50 percent of the space time, for 16 predictions. The algorithm fails to predict 6 of the 25 events at any decision rule threshold.

A Study of Heaton Pulse Using 2-D Burridge-Knopoff Model

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We use a 2-d Burridge-Knopoff model to simulate the rupture process in earthquakes. Slip pulses are observed in big events. In the contrast, no slip pulses develop in smaller events. We study the mechanism of the generation of Heaton pulses and find some factors which affect the generation of Heaton pulses. As an external factor, geometry of fault plane can be a cause of the occurrence of slip pulses. Boundary of strong barrier can generate healing waves which can cause the generation of slip pulses. Energy radiation as an internal factor can also influence the generation of Heaton pulses. In the case of large energy radiation, Heaton pulses develop in the early stage of fault rupture and the widths of Heaton pulses are narrow. But in the case of small energy radiation, Heaton pulses develop late and the widths of Heaton pulses are wide. Friction also play an important role in the generation of slip pulses. We use a mesoscopic model to study the friction between two rough surfaces and find that the collision between the vane-like teeth in the two rough surfaces can cause the healing of rupture and thus generate slip pulses during rupture process.

Dynamic Effects on Normal and Reverse Faulting

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The presence of a free surface affects the rupture dynamics of a seismic fault not only in the slip distribution but also by modifying the rupture propagation velocity. The reflection of elastic waves preceding the rupture at the surface and back-propagating onto the fault plane modifies the stresses significantly thus inducing a complex feedback effect on the rupture history itself. In the case of a normal fault nucleating at depth and propagating upwards, a stress concentration close to the surface may induce a shallow secondary nucleation anticipating up to a few seconds the arrival of the main rupture front. A change in the impedance of the medium, often quite abrupt in the surficial layers of the crust, will also have dramatic effects on the rupture history, locally amplifying the slip and biasing the estimation on deeper sections of the fault when extrapolating surface observations. These effects, explained by a simple stress analysis and illustrated by some numerical simulations for a few simple cases such as normal and reverse faulting breaking through the surface, could explain the observation of high frequency sources close to the surface in documented shallow earthquakes like Kalamata (Greece), 1986.

Dynamic Effects on Normal and Reverse Faulting

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We simulate the evolution of seismicity in a continuum model for a system of interacting faults with non-trivial geometry. In the case of in-plane deformation, a given system of strike-slip faults embedded in an elastic medium ends-up in locked situations because of geometrical incompatibilities. Mass (or compressive stress) accumulation on some portions of the fault close to a bend or kink monotonously increase with fault slip until the segment becomes locked and the system is unable to match the plate motion through slip. It is then necessary to include either thrust and normal faults in the model to alleviate the normal stress in the system, or to relax excess stress through some anelastic flow mechanism accounting for mass transport in the vertical direction. We introduce thrust and normal faults in the model and investigate the interaction between those two types of faults, and between competing segments of strike-slip faults. We then question the assumption of stationarity of seismicity on a system in which multiple faults interact.

Analysis of the Offshore-Onshore Data Collected During the 1994 LARSE Survey

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The 1994 LARSE (Los Angeles Region Seismic Experiment) survey included both airgun and explosion experiments conducted in the Los Angeles Basin and offshore borderland region. This study employs data recorded by 85 receivers along a line (Line 1) from Seal Beach to northwest of Barstow, including 4 stations on San Clemente and Santa Catalina Islands, and sources generated by an air gun (8400 cu. in.) along the seaward projection of this line. The portion of the data analyzed in the study includes over 1300 sources. Stations in the San Gabriel Mountains, Channel Islands, and some portions of the Mojave Desert show excellent recordings of various crustal phases. Stations in the Los Angeles Basin and some locales in the Mojave Desert show moderate to poor data. The geometry of the experiment is such that high-fold midpoints exist in the borderland and Los Angeles Basin area. This allows the gap between the marine MCS and land explosion components of the LARSE 94 survey to be filled in.

Lateral variations in the travel times and waveforms show that crustal structure in the area is quite complicated. An initial reconstruction shows a coherent sub-horizontal reflector in the mid crust. Examples of the raw data and results from the analysis of the seismic images of the crust beneath the Los Angeles Basin and offshore borderland region will be presented.

**Refraction/Wide-Angle Reflection Imaging of the Los Angeles
Region Using Onshore-Offshore Seismic Transects**

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The series of LARSE experiments was collected in '94-'95 by SCEC and the USGS to image on a crustal scale the tectonic framework of the Los Angeles metropolitan region including the Transverse Ranges, the LA-San Fernando-San Gabriel basins, and the offshore continental Borderlands. A major component of LARSE is refraction/wide angle reflection (R/WAR) profiling which here involved the use of land-based portable recorders to collect seismic airgun sources generated offshore by the R/V Ewing. This approach allowed for the collection of data which offers velocity and structural information of the full crust; the method was successful in light of the dense population of the LA region (14 million people) and the nearness of major tectonic elements to the coastline of Southern California.

During the acquisition of 16 multichannel seismic profiles by the R/V Ewing in the northern Inner Borderlands, 170 portable Reftek instruments were deployed in three major arrays in the LA region. Data quality ranges from excellent to poor. The best data on all three profiles were collected near the coastline, in the Transverse Ranges, and in the Mojave desert. Data quality rose during night shooting and when the weather was calm. Poor quality was generally collected in the urban portions of LA, particularly in the daytime (traffic). The Pg phase and possible intracrustal phases are visible in nearly all of the common receiver gathers for all three lines. The PmP phase is recorded at many stations. In spite of the major noise sources, possible Pn is observed at the quieter stations at offsets up to 200 km. The phases observed in these data will provide crustal-scale velocity and geometrical structure information of the LA metropolitan region.

* the LARSE working group includes the above plus Joyjeet Bhowmik and Michelle Robertson (USC); Janice Murphy and Uri Ten Brink (USGS), Katrin Hafner and Julie Norris (Caltech) and Mark Benthien (UCLA).

Industry Data from the San Fernando Valley and Ventura Basin

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The third of six scientific tasks as defined by the SCEC Science Director focuses on a multidisciplinary approach to study fundamental relationships among fault structures and dynamics. A contribution to this scientific task is the construction of the subsurface structural geometries of the LA basin and related Transverse Ranges fold and thrust fault system and their full crust configuration. These geometries will serve as a regional framework for other Task 2 (earthquake scenarios) and Task 3 (fault structure) studies and will also contribute to the construction of the master model. With the help of UCSB/ICS and OSU, SCEC was able to meet the conditions of the "Chevron challenge". In doing so, the scientific use of seismic profiles was granted to SCEC by Unocal, Western, and Chevron. In a separate challenge, well log information was made available to OSU by Chevron. The Chevron well log information are being analyzed by OSU. The Western seismic data is from the Ventura basin and surrounding region; the USGS is currently reprocessing these lines in attempts to obtain evidence reflections in the full crust via the use of extended correlation. USC is conducting similar reprocessing to the Chevron seismic data in San Fernando Valley. In addition, SCEC and USC are examining the basin and sub-basin portions of the profiles in order to create a structural model of SF Valley. In this poster we present the original industry profiles.

Three-Dimensional Simulation of Earthquakes on the Los Angeles Fault System

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We have used a 3-D finite-difference method to simulate 0-0.4 Hz ground motion from elastodynamic propagating ruptures with constant slip on faults in the metropolitan area of Los Angeles, California. Simulations are carried out for hypothetical M 6 3/4 earthquakes on the Palos Verdes and Elysian Park faults and, for comparison, an approximation to the 17 January 1994 M 6.7 Northridge earthquake. We use an elastic model (115 km by 95 km by 34 km) assembled by Magistrale and others which includes the 3-D structure of the Los Angeles and San Fernando basins.

Results show that, in general, sites associated with the largest peak motions and durations are located in the epicentral area, above the deepest parts of the basins and near the steepest basin edges. We find maximum peak velocities for the Palos Verdes, Elysian Park and Northridge simulations of 0.44 m/sec, 0.67 m/sec, and 0.58 m/sec, respectively. In each case, both the directivity of the rupture and the lower impedance of the basins

significantly amplify the ground motion. Signal durations at some basin sites are beyond 90 sec due to basin-edge generated waves. The Northridge simulation reproduces the overall spatial pattern of the long-period velocities generally within a factor of two and successfully predicts the timing of late arriving waves.

Sum of the Forces Driving Deformation in Southern California

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In an ideal transform environment, deformation is purely toroidal in nature. However, a plate boundary transform system is necessarily bounded by triple junctions requiring deformation accommodating contraction and dilation at the ends. Additionally, locally derived forces due to topography, variations in crustal thickness, and upper mantle density heterogeneity produce poloidal deformation. In southern California deformation is broadly distributed and the San Andreas fault is sinuous signifying the existence and relative importance of locally derived driving forces uncharacteristic of an ideal transform system.

Three-dimensional visco-elastic finite element models of the Pacific-North America (PA-NA) plate boundary in southern California have provided kinematically consistent estimates of the long-term velocity field. Simple dynamic models with uniform fault strength, no internally prescribed deformation, and a one-dimensional rheological structure produce a surface deformation field that differs significantly from that observed. Discrepancies between modeled and observed surface kinematics, especially poloidal motion, are indicative of regions where local forces may be important. Modeling substantiates that surface kinematics are sensitive to internally generated forces and that inclusion of these forces can produce a deformation field that closely resembles the observed deformation field. Including only topographically derived stresses, which can be well estimated, produces a field of convergence in the Salton Sea and dilation in the Transverse Ranges. However, observed dilation in the Salton Sea and contraction in the Transverse Ranges signifies that basally applied forces possibly induced by small scale convection in the upper mantle driven by sub-crustal density anomalies must be counteracting the topographic stresses. We evaluate the magnitude and style of deformation resulting from locally generated forces driven by density variations inferred from tomographic images of the upper mantle beneath southern California.

3-D MAPPING OF THE THIRTYMILE BANK DETACHMENT FAULT

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The Thirtymile Bank detachment fault forms the western edge of the San Diego Trough and parallels the Coronado Escarpment. In this study, the northern half of the fault, north of 32° 32' latitude, was examined and mapped. Using single-channel, high-resolution seismic profiles from three U.S. Geological Survey cruises and moderate-penetration seismic profiles from the 1990 USGS multichannel cruise, the depth of the fault was measured. Two-way travel time fault depth measurements were converted to depth values based on the seismic velocity analyses from the MCS profiles. With the fault

depths, a three-dimensional map of the fault was generated on the computer, and a contour map was drawn. The study finds the general characteristics of the fault including dip (10° to 23°), length (>100 km), and continuity. Younger high-angle normal faults offset the detachment forming seafloor escarpments in some cases. Seismically-active strike-slip faults also appear to intersect and offset the detachment along the axis of the San Diego Trough. The Thirtymile Bank detachment fault provides an excellent example of how major low-angle structures associated with the evolving PAC-NOAM plate boundary control and interact with youthful, seismically-active structures responsible for damaging southern California earthquakes.

An Integrated 3D-Velocity Inversion -- JHD Relocation Analysis of Events in the Northridge Area

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A subset of 3371 events recorded in the Northridge area by the SCSN during January-April 1994 was relocated with the JHD technique. The JHD locations are less scattered than the locations determined individually, but shifted about 3.9 km on average to the northwest of the latter. The station corrections vary between -0.55 sec and 1.26 sec. A 3-D velocity model for the area was determined using the arrival times of 1012 events. The initial velocity model was that used routinely by SCEC. The first two layers show pronounced low-velocity anomalies that correspond to the west Ventura and Los Angeles basins. Analysis of synthetic arrival times generated using the 3-D velocity model shows that the JHD locations are affected by a quasi-systematic shift (of about 2.5 km on average) in a northwest direction, but that the relative locations are well preserved. To account for this mislocation, an overall shift of 2.5 km to the southeast was applied to all the actual JHD locations. One of the most important implications of these shifted locations is the possibility that the northeasterly-dipping Santa Susana fault was seismically active during the aftershock sequence.

Seismic Hazard Mapping by the California Department of Conservation, Division of Mines and Geology, in Los Angeles, Ventura, and Orange Counties, California, Affected by the January 17, 1994 Northridge Earthquake

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A multi-year project is underway to assess the seismic ground motion, liquefaction, and landslide hazards and produce seismic hazard zones in the areas affected by the January 17, 1994 Northridge earthquake (M_w 6.7) and other high-risk urban centers of California in fulfillment of the mandates of the Seismic Hazard Mapping Act of 1990, and to assist state and local government agencies in making regional hazard and risk mitigation decisions. The seismic ground motion hazard estimates were calculated for 10% probability in 50 years using the source model of the Southern California Earthquake Center, modified with additional slip rate information for mapped faults and blind thrusts. Attenuation relations for peak horizontal acceleration and spectral acceleration at 0.3 and 1 s periods on alluvium, soft rock, and hard rock site conditions were used to calculate the hazard maps. A geologic map that differentiates alluvium, soft rock, and hard rock site

conditions was produced from existing geologic maps and overlaid with the ground motions exceeding 0.4 g (pga), 0.8 g (0.3 s SA) and 0.4 g (1 s SA) nearly everywhere. Using only the background seismicity yields hazard estimates ranging between 0.3 to 0.45 g for pga at 10% in 50 years. Therefore, the ground motion hazard is quite high regardless of which seismic source model is assumed.

A Monte Carlo uncertainty analysis was performed to analyze the range of ground motions that could be obtained from this source model and to analyze the importance of each of the input parameters of the source model. The overall uncertainty (95% confidence) is about 50% of the mean ground motion hazard estimate. The magnitude-rupture length relations, attenuation relation, magnitude-frequency distribution, and slip rates contribute most to the uncertainty of the hazard estimates. In addition, the predominant seismic source distance and magnitudes were mapped across the tri-county area and indicate that the San Andreas, San Jacinto and Elsinore faults dominate the hazard in southern California, except in portions of the Los Angeles basin, the south coast, and in the Ventura basin.

Zonation for seismically-induced ground failures is currently underway for use in identifying where site-specific investigations will be required for new construction. Provisional hazard maps have been prepared using a simplified hazard assessment methodology that integrates surface geology, topography, and groundwater information using GIS technology. Geologic units were classified according to strength criteria for liquefaction and slope stability respectively, and mapped over the area most heavily damaged by the Northridge earthquake. The surface extent of these units was spatially intersected with areas of shallow groundwater for liquefaction hazard, and with slope categories for landslide hazard to identify the aerial extent of hazard susceptibility. About one-third of the mapped area is classified as high hazard susceptibility, with the area covered by potential landslide and liquefaction hazard roughly equal. Although over 80% of the land affected by slope failures during the Northridge earthquake fall in the high-hazard areas, the total high-hazard area is conservative given the methods used. Subsurface geotechnical data, higher resolution terrain models, and careful calibration of terrain units with failures during the Northridge earthquake should result in more reliable delineation of seismic hazard zones.

Elastodynamics of Rupture Propagation and Arrest

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We report numerical simulations of slip evolution along a 2D vertical strike-slip fault in an elastic half-space, using a framework incorporating rate- and state-dependent friction and fully inertial elastodynamics, like in Rice and Ben-Zion [Proc. NAS, '95]. The model is a follow up on earlier quasistatic [Tse and Rice, JGR, '86] and quasidynamic [Rice, JGR, '93; Ben-Zion and Rice, JGR, '95] simulations of deformations along smooth fault systems in elastic continua. The fault is driven below 24 km by a constant plate velocity of 35 mm/yr and slip histories are calculated over the shallower zone, where rate and state frictional parameters are prescribed as in Rice ['93]. The elastodynamic calculations are based on the spectral method of Perrin et al. [JMPS, '95] and a new algorithm [Rice and Ben-Zion, '95] which allows accurate treatment, within a single computational framework, of long slow deformation phases of order 100 yr., short periods of rapid dynamic instabilities of order seconds, and the transitions between those modes. Detailed examinations of model earthquakes show the following features: Instability events are preceded by a nucleation phase of accelerating creep which expands in space. When the nucleation phase reaches a critical size, dynamic instability occurs. The rupture propagates

usually first toward the free surface and is then reflected back downward triggering a large slip event. The calculations with full elastodynamics thus show wave phenomena not simulated by quasidynamic calculations. Also, final slip values of model earthquakes in full elastodynamic calculations are larger than those of corresponding quasistatic/dynamic events. However, examinations of long histories (e.g., 1000 yr) of simulated slip indicate that the overall results are similar to those obtained by the corresponding quasistatic/dynamic calculations. Slip histories along a smooth fault show only quasi-periodic large events. This is compatible with our previous conclusions [e.g., Ben-Zion and Rice, '95] that the origin of observed broad distributions of event sizes is strong fault zone heterogeneities.

Paleoseismic Evidence of Large Slip Earthquakes on the Sierra Madre Fault in Altadena, California

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The potential for earthquakes along reverse faults in the Los Angeles region has been dramatically illustrated by the damaging San Fernando, Whittier Narrows, and Northridge earthquakes in 1971, 1987, and 1994 [Kamb et al., 1971; Hauksson and Jones, 1989; Hauksson et al., 1994]. These earthquakes have sparked fundamental questions regarding the potential size of earthquakes generated along reverse faults in the greater Los Angeles region.

Previous work suggests that the Sierra Madre portion of the frontal fault system appears to have a significantly lower slip rate than other portions of the frontal fault system, namely the Cucamonga fault to the east and the San Fernando fault to the west [Bull, 1978; Crook et al., 1987]. Yet some of the highest topography of the San Gabriel Mountains is located above the Sierra Madre fault that is presumed to be less active.

We recently excavated across the Sierra Madre fault, just east of Lincoln Avenue and north of Loma Alta Drive in Altadena (Figures 1 and 2). Geomorphic evidence of prehistoric deformation along the Sierra Madre fault at the Loma Alta Park site consists principally of a >4 m scarp that cuts a late Quaternary geomorphic surface. The trench crossed the well-exposed scarp immediately north of the parking lot of Loma Alta Park. This uplifted terrace no longer receives active deposition and lies between the deeply incised Millard Canyon on the west and West Ravine and Chiquita Canyon on the east.

In the excavation, the lowest exposed stratigraphic unit is crudely stratified and locally imbricated, boulder to pebble size gravel with a coarse sand matrix (Unit 1). Overlying the coarse gravel is a fine sandy gravelly loam (Unit 2). A paleosol (B_t horizon), up to 50 cm thick, is exposed within the fine-grained alluvium and the uppermost coarse gravels. Overlying the fine-grained alluvial unit is a wedge-shaped deposit of massive, pebbly, coarse to fine sand (Unit 3). Based on its massive texture, matrix support, and shape, we interpret this unit as a scarp-derived colluvial wedge. The two alluvial units, the buried soil, and colluvial wedge are found in the lower plate of a gently north dipping fault. Only the coarse alluvium is present in the upper plate. A massive unfaulted unit of boulders and gravel in a silt and sand matrix (Unit 5) overlies the fine-grained alluvium and colluvial wedge. This gravel unit thins southward and laterally grades into silty sand and

represents a colluvial wedge that formed from the collapse and modification of the scarp following the most recent surface rupture. The Sierra Madre fault appears in the trench wall as a single trace, with minor faults in a zone about 0.5 m wide within the upper plate of coarse alluvial gravels. Locally imbricated beds of gravels are cut by the fault. Radiocarbon analysis of detrital charcoal from both colluvial wedges is in progress at the Accelerator Mass Spectrometry Laboratory at the University of Arizona.

The trench exposed stratigraphic evidence of at least two prehistoric earthquakes. The two colluvial wedges represent deposits formed immediately following surface rupture. The lower colluvial wedge (Unit 3), fine-grained alluvium (Unit 2), and buried soil have been faulted and subsequently eroded from the upper plate. The colluvial wedge that contains southward-thinning coarse gravels (Unit 5a) lies directly above the fault zone and is the primary evidence for the most recent earthquake. In order to resolve slip from the most recent earthquake, we restored the dip slip component of motion along the fault. Restoring the tip of the upper plate to the tip of the lower colluvial wedge (Unit 3) gives a minimum of ~3.8 - 4.0 m of slip from the most recent earthquake. This restoration reveals the approximate geometry of the alluvial and colluvial beds prior to the most recent earthquake. Several lines of stratigraphic evidence indicate a penultimate earthquake on this fault. The presence of a second colluvial wedge (Unit 3) and the truncation of the sub-horizontal fine-grained alluvium (Unit 2) and B_t horizon below the fault zone is evidence for a previous event. Restoration of the upper plate to below the B_t horizon yields a cumulative minimum slip of ~9.5 m for the last two events. Here, we assume the B_t horizon and the fine-grained alluvium was continuous across the upper plate and use projection of the average dip of the base of the B_t horizon to constrain the reconstruction. If the upper surface of the scarp is palinspastically restored to yield a smooth initial paleosurface, total cumulative slip is ~10.5 m. Work is continuing at the Loma Alta site to better constrain the age of the surfaces and soil correlations across the fault.

Based on the slip in the most recent earthquake, we can infer the size of this event. One approach is to use the regressions relating the parameters of maximum surface displacement and average surface displacement to moment magnitude [Wells and Coppersmith, 1994]. Using 4 m as the maximum displacement yields a M_w of 7.1. If we assume 4 m represents the average surface displacement, the relations predict a M_w of 7.4. Another approach to estimating earthquake magnitude is to calculate the seismic moment. Assuming an average slip of 3.0 to 4.0 m, a strike-length of 65 km (Tujunga to San Antonio Canyon) to 90 km (Tujunga to San Jacinto fault), and a seismogenic depth of 15 to 20 km, the estimates of the seismic moment for the most recent earthquake range between 1.13 x 10²⁷ dyne-cm and 3.49 x 10²⁷ dyne-cm. Converting the seismic moment to moment magnitude, using the equation M_w = (log M₀ - 16.1/1.5) [Hanks and Kanamori, 1979] yields a M_w from 7.4 to 7.7 for the most recent earthquake. The large amount of slip in the penultimate event also suggests an earthquake of similar size. Until more paleoseismic studies along the fault yield information on rupture length and distribution of slip, there will be significant uncertainty in estimating the size of past earthquakes. However, our paleoseismic data from the Loma Alta site implies that the past two earthquakes were M7+ events.

The prehistoric earthquakes at the Loma Alta site appear to be significantly larger than other historical earthquakes along reverse faults in the greater Los Angeles region in 1971, 1987, and 1994. Large displacements suggest that the Sierra Madre fault breaks across multiple, relatively short segments [as defined by Crook et al., 1987], unlike the 1971 event that ruptured a single segment.

MODELING STRONG GROUND MOTIONS IN THE LOS ANGELES BASIN

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Our main objective in this work is to investigate the strong motion characteristics of a scenario earthquake on the San Andreas fault for sites located in the Los Angeles basin. Preliminary calculations have concentrated on the simulation of a hypothetical Mw 7.9 event for a profile of sites across the Los Angeles basin using a 1D velocity structure model. The results of the 1D calculations provide a framework that can be modified to incorporate the ground motion effects due to 2D and 3D structural variations in the Los Angeles basin. Before addressing the importance of basin effects for the San Andreas event, we need to first validate our basin structure model and our 3D simulation procedures using strong motion data recorded from previous events. To investigate these issues, we have performed simulations of the 1987 Whittier Narrows earthquake using a 3D elastic finite-difference modeling algorithm. Our simulation results accurately reproduce many of the features that are seen in the strong motion recordings, including the general amplification of ground motions within the basin, and the occurrence of strong multiple arrivals and extended durations at many of the basin sites.

A Granular Model of Brittle Mechanics: Earthquakes, Fault Zone Stresses and Seismic Energy

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The basic process responsible for earthquakes and faulting is not known. The intuitive notion of frictional slip on faults between elastic crustal blocks cannot be reconciled with laboratory measurements of the strength of rocks, field observations of heat flow and stress orientation around the San Andreas fault, and seismological estimates of the energy radiated by earthquakes. An alternate paradigm for the mechanics of the crust is proposed, based on a granular model of brittle materials. Numerical simulations of the deformation of an aggregate of rough grains under compressive stress show earthquake-like elastodynamic failures without frictional heat production, and substantial rotation of stresses across shear zones.

A feature of this model is that all the strain energy in earthquakes is released as elastic waves, which appears to contradict seismological estimates of radiated energy. However, the dominant wavelength in the wave energy produced in the simulations is the same as the scattering length in the surrounding material. Only a fraction of the energy is carried by coherent, longer-wavelength radiation, while the remainder is strongly scattered and remains trapped near the source. There are parallels here with the ideas of acoustic fluidisation in fault zones during earthquakes, Anderson localisation in granular materials, and the barrier model of heterogeneous seismic sources.

Crustal Deformation Across and Beyond the Los Angeles Basin from Geodetic Measurements

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We combine six years of Global Positioning System data with 20 years of trilateration data and a century of triangulation, taped distance, and astronomic azimuth measurements to derive 67 interseismic station velocities in the greater Los Angeles region. We interpolate the velocities to construct a regional strain map beyond the Los Angeles basin. Our results generally agree with the model proposed by the 1994 Working Group on California Earthquake Probabilities. Important regional findings of this study are as follows. (1) There is a significant north-south convergence and east-west extension, about $0.19 \pm 0.04 \mu\text{rad/yr}$ for both components, along the southern frontal fault system of the San Gabriel Mountains. (2) The crustal deformation around the Big Bend of the San Andreas fault demonstrates wrench-style motion across the San Andreas fault. However, such deformation cannot be solely explained by fault-parallel slip beneath the surface expression of the San Andreas fault. Decollement beneath the San Gabriel mountains with a combined left-lateral and shallow thrusting motion of up to 10 mm/yr may help to explain the residuals to the Working Group model. (3) Strong compression is found along the Malibu-Santa Monica-Raymond Hill fault system, where the maximum compression direction rotates gradually from north in the eastern section to north-northeast in the western section. There is little east-west extension along this fault system.

Complexities of Source Inversion and Wave Propagation in Southern California

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We have been working on realtime source inversion and ground motion estimation (Scrivner and Helmberger, 1995). Our initial attempts employ a simple 1-D velocity model for the entire Southern California region. This model fits long period energy in the data well, but we are constantly surprised by features in the high frequency energy. The recent 17 August 1995 China Lake earthquake is presented as an example of this fact. A record section of most of the current TERRAScope stations and a few of the new K2 network stations are compared to synthetic waveforms produced with this model and source parameters found by Dreger (pers. comm.). An analysis of seismic energy recorded along the section has been done to determine the ratio of energy scattered into the mantle to that trapped by the crustal waveguide. The record sections highlight a problem with using a single simple model. Even at regional distances, the difference in ground motion amplitude between nearby hard- and soft-rock sites can be enormous. Similarly, earthquakes from a complex source region can be difficult to invert because the wave propagation is strongly affected by structures around the source. Aftershocks of the 1994 Northridge earthquake provide a rich dataset of regional and local data for studying these problems. We have done source inversions on a number of aftershocks with broadband TERRAScope data and timing from local stations. Depth determination is difficult because of the complex structure of the San Fernando basin. We are modeling the local data with 2-D finite difference structures in an attempt to improve our understanding of the velocity structure of the basin

and its effects on propagation. This may also be useful for improving our depth determinations for the aftershocks.

Listric Faults and Related Folds, Uplift, and Slip

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Fault related fold models have been applied worldwide to determine geometry and slip rates of blind faults. The following predictions are made by these existing models:

- * Fault slip is greater than or equal to back limb length (fault bend folds)
- * Syn-tectonic sediments acquire dip "instantaneously", with no progressive limb rotation (both fault bend and fault propagation folds).
- * The uplift rate is constant above fault ramps.

We have tested these models in the western Transverse Ranges province of southern California, and found that these predictions are not supported by the data for several structures. Much of the slip predicted from fold back limb length is not accounted for. High resolution seismic reflection profiles and dated marine terraces record progressive down to the north tilting during Quaternary time over at least a 60 km stretch of the southern margin of Santa Barbara basin.

We propose a new non-planar model for blind faulting and related folding. Long back limbs with infinitesimal dip form instantaneously above listric (concave up) segments of faults. Dip and vertical separation increase with increasing slip. The following predictions are made by our new listric fault model:

- * Slip can be much less than limb length, or it can be more.
- * Fold limb rotation (tilting) is progressive.
- * Uplift rates are maximum above the steepest part of the fault.

GEOMORPHOLOGIC CONSTRAINTS ON THE UPLIFT AND NEOTECTONICS OF THE SAN BERNARDINO MOUNTAINS, SOUTHERN CALIFORNIA

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The San Bernardino Mountains contain a complicated system of interacting faults associated with Quaternary uplift, whose geometry and kinematics are not yet fully characterized. Many of these are potential seismic sources, such as the unrecognized fault responsible for the 1992 Big Bear earthquake. To better understand the complex neotectonics, we attempt to constrain the range uplift using geomorphology.

The San Bernardino's are the highest and most massive range in southern California. In comparison to other ranges, they also have a more complex, heterogeneous

distribution of elevation and slope. We divide the range into 14 distinct domains on the basis of self-similar morphology. We then rank them in order of relative maturity based on their first-order morphologies; the least mature are east-west ridges in the south, followed by the northern and southwestern margins, the eastern and western flanks, and the central plateau. From this ranking and the relative geometries of the domains, we create a rough model for the evolution of the mountain surface. This preliminary model emphasizes that the range uplifted as independent, fault-bounded blocks with unique timing and kinematics.

Analysis of drainages shows a similar distribution of maturity that strengthens the first-order model. Airphoto interpretation of the whole range (in progress) quantifies geomorphic features such as landslides, terraces, and erosion surfaces to further enhance the model. Airphoto analysis also provides direct information on the distribution and character of active structures, which may also lead to future research.

Site Effect Study in the San Fernando Basin, Los Angeles, California: A Comparison of Methods

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During the months that followed the 17 January 1994 M6.7 Northridge, California earthquake, portable digital seismic stations were deployed in the San Fernando and Los Angeles region to recover aftershock data. One of the goals of this deployment was to examine the seismic hazard in this urban environment by way of site-specific amplification factors. In a preliminary study using 7 events we calculate amplification at 17 sites using a variety of the "standard" techniques and compare the results. We compare site response estimates which use the two horizontal components of ground motion as a complex signal with estimates which use only a single component or the geometrical mean of the site response estimate from each component. We compare whole record estimates of the site response with estimates which window the s-wave and coda-wave portions of the data. We also compare horizontal coda-wave with vertical coda-wave site response estimates. We find that the vertical coda-wave site response estimates tend to give larger amplification factors than horizontal coda-wave estimates. We also find that the vertical and horizontal coda-wave estimates both produce larger amplification factors when compared with the horizontal s-wave or whole record estimates.

Validation of Coulomb Stress Change Calculations for the 1994 Landers Earthquake by Comparison with Postseismic Fault Slip and Seismicity Rate Changes

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Three groups [Harris & Simpson, Nature 1992; Jaumé & Sykes; Stein et al, Science 1992] calculated that the San Bernardino Mtn. segment of the San Andreas was brought ~5 bars closer to failure by the 1992 M=7.4 Landers earthquake. We show here

that the seismicity rate change after the earthquake is also in close accord with the calculated stress change. Treating the San Andreas as a freely-slipping boundary element subjected to the stress perturbation of the Landers earthquake, Stein et al also calculated that to shed the stress imposed by Landers, the San Andreas would have to slip 10-20 cm at San Bernardino, and either stop or slip backwards near Palm Springs. Subsequently published GPS surveys, strain measured at Piñon Flat Observatory, and surface creepmeter data [Shen et al; Wyatt et al; Bodin et al, BSSA, 1994] are in close accord with the stress predictions, suggesting that in the weeks to months after the Landers earthquake, the San Andreas slipped 10-12 cm where the stress was raised, and stood still or slipped backwards where the stressed dropped. These observations support the validity of the stress calculations, and reveal that a fault 40 lip in a matter of weeks what would normally take nearly a decade. What this means for the earthquake hazard to the residents of southern California's 'Inland Empire' near the San Bernardino segment of the San Andreas is, however, less clear. The simplest interpretation is that the San Andreas released the stress transferred by Landers soon after the earthquake, and thus Landers will have no longterm influence on the timing of the next great San Andreas shock. The data of Shen et al, however, suggest that post-Landers slip on the San Andreas fault was concentrated at depths >10 km, in which case ductile creep in the lower crust may have further concentrated stresses in the seismogenic crust, magnifying Landers' effect and advancing the time to the next great San Andreas event.

Differences in Seismic Hazard for Three Earthquake Scenarios of the Los Angeles Region

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We illustrate differences in estimates of seismic hazard in the Los Angeles region resulting from the assumption of the three earthquake scenarios presented by Dolan et al., (1995). The scenarios differ in the size of earthquakes assumed to occur on each fault. Either; (1) large earthquakes rupture the entire length of each fault, (2) moderate-to-large earthquakes rupture between major discontinuities or bends in fault trace, or (3) moderate earthquakes (such as the 1994, M6.7 Northridge earthquake) rupture small areas of each fault and overlap with other ruptures. The differences are illustrated in maps of peak ground acceleration at 10% probability in 50 years for each scenario, and maps of the differences in peak acceleration between the scenarios. The largest differences in peak acceleration between the earthquake scenarios are about 0.3g. The larger differences tend to occur (1) where a number of faults intersect or are in close proximity to one another, (2) along some of the fastest slipping faults in the region, and (3) where major discontinuities or bends are present along the faults. The latter is either an artifact or consequence of the assumed fault segmentation models and, hence, the locations of the assumed segment boundaries. Elsewhere in the region, differences between the three maps are generally less than 0.1g.

Reference Dolan, J. F., Sieh, K., Rockwell, T. K., Yeats, R. S., Shaw, J., Suppe, J., Huftile, G. J., and Gath, E. M. 1995. Prospects for larger or more frequent earthquakes in the Los Angeles Metropolitan Region. *Science* 267: 199-205.

Aseismic Crustal Velocity Map of Southern California

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The Global Positioning System (GPS) data of the TREX experiments (Feigl et. al. 1993) from 6/1986 to 5/1992 and the High Precision GPS Network (HPGN) from 4/1991 to 3/1994 are used to estimate the aseismic crustal velocity over a broad area of Southern California from 32.5N to 36.0N.

The GAMIT solutions of 180 observation sessions (including some global GPS data) are combined together to estimate the station velocities and positions, satellite orbital and earth rotation parameters using the GLOBK software package. Prior station velocities are predicted values from a block-dislocation model based on trilateration, VLBI, and GPS data developed at UCLA. We also make coseismic corrections for the Landers (6/28/1992) and Northridge (1/17/94) quakes using observed and modeled values obtained from independent geodetic data. Corrections to the coseismic displacement are estimated along with other parameters in the GLOBK solution.

Except for the HPGN sites in the Mojave and north of Garlock fault, the velocities of most sites are well resolved by the data and are consistent with the prior model. Several HPGN sites with larger velocity deviation might have unmodeled coseismic displacement.

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

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Comparison of four hammer or nail gun reflection profiles with coincident Mini-Sosie data suggest that the quality of images for the upper 100 feet of the subsurface are influenced by at least four factors. First, the more the spread apertures of coincident profiles overlap, the better their events will correlate. Second, features logged in trenches within the upper 1 m can be imaged with a high frequency nail gun source and careful processing. Third, although small apertures are needed to record very shallow subcritical reflections, they ensure that surface waves will degrade the image at shallower depths as well. Reflected surface and air waves also pose greater problems with small apertures and their hyperbolic moveouts make them difficult to identify in the field. Finally, optimal recording parameters and processing approaches for hammer experiments varied significantly along the length of a single Mini-Sosie profile. Optimal recording parameters from hammer wave tests most resembled those of the Mini-Sosie experiment where Mini-Sosie reflections are brightest. Where reflections are dimmer, optimal hammer parameters differed from those of the Mini-Sosie experiment. Nail gun wave tests produced the best reflections where small spread apertures were optimal.

Active and Late Cenozoic Tectonics of the Northern Los Angeles Fold-and-Thrust Belt, California

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The northern Los Angeles fold-and-thrust belt contains potentially seismogenic structures directly beneath major population centers of the Los Angeles metropolitan area. For a better assessment of seismic hazard, we mapped active and late Cenozoic faults and folds in the northern Los Angeles basin, using an extensive set of oil-well and surface geologic data. We identified three distinct stages of tectonic deformation of the northern Los Angeles fold-and-thrust belt since the early Miocene: (1) early to late Miocene extensional stage, (2) latest Miocene to early Pleistocene contractional stage accompanied by a left-lateral strike-slip fault at the southern range front of the Santa Monica Mountains, and (3) middle Pleistocene to Holocene contractional and strike-slip stage. Many faults were initiated as normal faults in the early to late Miocene and were later reactivated as reverse faults, suggesting that the orientation of reverse faults is controlled by Miocene extensional tectonics rather than the Pliocene-Pleistocene stress field. Most of the active structures were initiated in the final stage, including the surficial West Beverly Hills Lineament and the blind North Salt Lake fault, Hollywood basin, and Wilshire fault. The West Beverly Hills Lineament is the northernmost segment of the Newport-Inglewood fault zone, which may have propagated northward to the Santa Monica Mountains in the Quaternary. The active Santa Monica-Hollywood fault system is divided into distinct segments by the cross-cutting West Beverly Hills Lineament. The Hollywood basin and North Salt Lake fault are pull-apart structures associated with left slip on the Hollywood fault and right slip on the West Beverly Hills Lineament. The uplift and southward tilting of the oxygen-isotope substage 5e marine terrace north of the City of Santa Monica suggest an average dip-slip rate of as large as 1.5 mm/yr for the Santa Monica Mountains blind thrust fault underlying and uplifting the Santa Monica Mountains. This rate is two to four times less than a previously reported slip rate averaged over the past 2.0-3.0 million years based on a balanced cross section. An average left slip rate of 2.8-6.8 mm/yr for the Malibu Coast-Raymond fault in the past 6.5 million years is also significantly larger than a slip rate during the late Quaternary. Because the pattern of Quaternary deformation in the northern Los Angeles basin is considerably different from that of Pliocene deformation, a slip rate averaged over the past several million years is not representative of that in the later Quaternary. Crustal shortening across the northern Los Angeles fold-and-thrust belt accounts for as much as half of a shortening rate of 5 ± 1 mm/yr between the San Gabriel Mountains and Palos Verdes Hills estimated using GPS observations.

SCEC Strong-Motion Database SMDB and Empirical Green's Functions Library EGFL

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SMDB is used by scientists and engineers from 33 institutions in the US, Canada, France, Germany, Italy, Japan and UK. During the last year we added Northridge data from USGS, CDMG and USC as well as response spectral ordinates at 0.3, 1 and 3 s. The Web page for SMDB is at <http://quake.crustal.ucsb.edu/scec/smdb/smdb.html>.

We are now putting data into EGFL. EGFL allows to search through parameters of seismic records, access unclipped and low-noise records and process them with SAC, plot

selected earthquakes and stations and interactively obtain additional information from the maps. We have already processed all TERRAscope data and started working on SCSN data.

Performance of EGFL and SMDB will be demonstrated on a stand-alone SUN workstation.

Empirical Time-series Simulation of Phase III Scenario Earthquakes: A Hybrid Approach

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We present a hybrid approach to ground motion prediction. First we perform a kinematic modeling of a scenario earthquake with synthetic Green's functions. Assuming a constant ratio of the slip over the rise time (constant stress drop) we achieve an excellent stability of predicted velocity and displacement waveforms regardless of the distribution of slip on the fault. The major problem with any method based on synthetic Green's functions is that our propagation models may incorrectly represent path and site velocity structures, attenuation etc. The best way to reduce these errors is to calibrate our methods utilizing observations of past earthquakes.

In practice it is not uncommon to have only one good recording of a small earthquake at a given site. Moreover this event should not necessarily originate within the anticipated large earthquake rupture area. However by predicting the small earthquake's response with synthetic Green's functions we obtain a transfer function between the predicted and observed waveforms. This empirical transfer function accounts for inaccuracies in the theoretical path and site models, as well as the small event's source model. Thus even a single event's empirical transfer function can be used to improve results of a purely theoretical forward modeling.

We will show application of this approach to the Northridge earthquake using data from the SCEC portable deployment.

Slip History of the 1995 Kobe, Japan, Earthquake Determined from Strong Motion, Teleseismic, and Geodetic Data

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Near-source ground motions, teleseismic body waveforms, and geodetic displacements produced by the 1995 Kobe, Japan, earthquake have been used to determine the spatial and temporal dislocation pattern on the faulting surfaces. A linear, least-squares approach was used to invert the data sets both independently and in unison in order to investigate the resolving power of each data set and to determine a model most consistent with all the available data. A two-fault model is used, with a single fault plane representing faulting under Kobe and another plane representing slip beneath Awaji Island. The total seismic moment is estimated to be 2.8×10^{26} dyne-cm (M_w 6.9), with rupture partitioned such that half the slip was relatively deep (5-20 km) and northeast of the epicenter toward Kobe, and half was to the southeast and shallower (0-10 km) beneath Awaji Island. Analysis of the final slip model indicates that the ground motions recorded in the severely damaged region of Kobe originated from the region of relatively low slip (1-1.5 meters), deep beneath Kobe and not from other areas of the rupture with larger slips (i.e., 3 meters, shallow beneath Awaji Island).

**Slip Distribution for the 1994 Northridge Earthquake:
What Features Can Individual Data Sets (Strong Motions, GPS, Leveling,
Teleseismic) Resolve?**

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We have examined the slip history of the Northridge earthquake by inverting, both separately and in unison, a variety of data sets including near-source ground motions, GPS displacement vectors, leveling-line uplifts, and teleseismic bodywaves. We also used the models determined from individual data sets to predict the other data, thereby testing their overall validity. The relatively deep slip and small source dimensions of the Northridge rupture test the limit of resolution for each data set, particularly for shorter wavelength details. Since the ability of the GPS data to resolve details of the slip pattern diminishes greatly with depth, some of the deep slip variations which are needed to explain portions of the ground-motion waveforms are not imaged. Considerably different details in the slip pattern at depth give rise to only small differences to the GPS fits, indicating that the GPS data alone cannot resolve the deep slip. Further, the model determined from only GPS data does not adequately reproduce the strong-motion characteristics. Whereas a particularly smooth slip pattern is sufficient to satisfy the geodesy, the strong-motion data require a more heterogeneous slip distribution in order to reproduce the waveforms. Likewise, comparison of the strong-motion fits from the strong-motion model to those fits of the combined model---which have fairly different slips---shows only minor degradation to the waveform matches, indicating limited resolution of the slip details. Further, the GPS displacements are not well predicted by the strong-motion model. The teleseismic data requires only deep slip, and shares most features of the strong-motion model; it does not, however, predict the other data well. We conclude that, given the specific data and source parameters of the Northridge earthquake, neither the teleseismic, strong-motion, or geodetic data alone have the resolving power to adequately recover the detailed source slip heterogeneity. Consequently, an adequate representation of the source requires the combined analysis of these data sets.

**A Synthetic Seismicity Model for Southern California: Cycles,
Probabilities, Hazard**

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The absence of a long catalog of observed seismicity with which to constrain earthquake recurrence behaviors is a fundamental stumbling block to earthquake prediction in California. Conceding that this limitation is not likely to relax in the foreseeable future, alternative approaches must be sought to extend the catalog artificially. In this article, I evaluate the long term behaviors of earthquakes on a map-like set of southern California faults through computer simulations that incorporate the physics of earthquake stress transfer and are constrained by excellent, but restricted, bodies of geological and seismological data. I find that model seismicity fluctuates on both short (~10 years) and long (~200 years) time scales, but that it possesses a well defined mean and standard deviation. Seismicity fluctuations correlate across different magnitudes, and the long term cycles of smaller events seem to lead cycles of larger events. Short-period seismicity fluctuations do not exhibit this tendency and short term changes in low magnitude (M5+)

seismicity are not likely to be an effective predictor of future large events, at least for the region as a whole. As do real faults, the model faults produce characteristic and power-law quakes in variable ratios with diverse periodic and non-periodic behaviors. Generally, larger events tend to occur quasi-periodically, and smaller ones tend to cluster; however only for a few earthquake classes and certain locations is recurrence notably non-Poissonian. A premiere use of synthetic seismicity is in the construction of earthquake hazard maps because it obviates many ad-hoc assumptions regarding frequency-magnitude distributions, multiple segment failure statistics, and rupture extents, while satisfying a spectrum of geological constraints such as fault slip rate, segment recurrence interval and slip per event. With its depth of temporal and spatial coverage, synthetic seismicity also provides a means to investigate the time dependence of seismic hazard. Because hazard likelihood is a concatenation of the recurrence statistics from many seismic sources, in only about 40-50% of the regions near the major faults do sequences of 0.1g or 0.2g exceedences differ from Poissonian.

Two-Dimensional Simulation of Northridge Aftershocks

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We have used 2-D elastic finite-difference methods to simulate 0-3 Hz P-SV and SH waves for three M 4.1 Northridge aftershocks with epicentral locations near the northern edge of the San Fernando Valley. Our model is a vertical, approximately N-S striking, cross section of a 3-D geological model developed by Magistrale and others which includes the velocity structure of the Los Angeles and San Fernando basins.

The simulations show multiply reflected phases and dispersive surface waves propagating southward from their apparent generation at the northern edges of the San Fernando and Los Angeles basins.

To validate the simulations we compare the synthetic records to seismograms recorded by three-component digital instruments along the profile where the cross section was taken. The aftershock simulations reproduce the peak velocities along the profile generally within a factor of two but mostly underpredict the durations.

***SCEC Summer Intern**

Observation of Log-periodic Activity in the Regional Seismicity Before and After the May 2, 1983 M=6.5 Coalinga Earthquake

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Regional seismicity was analyzed before and after the 1983 Coalinga earthquake in central California, with the objective of looking for power law behavior decorated with log-periodic fluctuations. As pointed out by Sornette and Sammis (1995), these phenomena are expected if an earthquake can be viewed as a critical point analogous to many phase transitions. The region analyzed was chosen to reflect the natural spatial clustering in the 8 years preceding the event. The regional preshock seismicity pattern was optimized with respect to lower magnitude cut-off and measure of activity (cumulative number vs. Benioff strain vs. energy). We found that the best signal was obtained by fitting the Benioff strain of preshocks with $M_L \geq 3.5$. Log-periodic fluctuations about the Omori aftershock law were reported by Eaton (1990). We have also optimized this signal with respect to the magnitude cutoff and the measure of seismic activity.

***SCEC Intern**

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

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Borehole elongation in 46 drill holes in Southern California was used to infer breakout orientation and directions of maximum horizontal principal stress (SH_{max}) for five areas: Barbara area, Upper Ojai Valley, Central Ventura Basin, East Ventura Basin/Central Transverse Ranges, and the Los Angeles Basin. Directions of SH_{max} generally vary from N-S to NE-SW throughout the region, although NW-SE directions are locally present in the San Fernando region.

Breakouts were determined from analysis of oriented 4-arm caliper data (raw dipmeter logs) available at the state Division of Oil and Gas. The breakouts form at the position of the maximum compressive stress on the borehole wall; if the borehole is vertical and parallel to one of the principal stress directions, the breakout will form parallel to the minimum horizontal principal stress Sh_{min} , and SH_{max} will be orthogonal to it. Observations from deviated boreholes permit some constraints on the relative magnitudes of the principal stresses.

In most cases the data permit either a thrust faulting ($S_v < Sh_{min} < SH_{max}$) or strike-slip faulting ($Sh_{min} < S_v < SH_{max}$) stress regime. The directions of SH_{max} were as follows: Santa Barbara: N-S; Upper Ojai Valley: N20E; Central Ventura Basin: N47E; East Ventura Basin/Central Transverse Ranges: N50E; Los Angeles Basin: N36E.

These results are broadly consistent with results from focal mechanism studies [Hauksson, 1990] as well as breakout and focal mechanism data present in the world stress map database [Zoback, 1992]. However, we see systematic variations in SH_{max} directions that are larger than seen in much of the data previously reported for the region. An anomalous NW-SE direction of SH_{max} in the San Fernando Valley region and easternmost Central Transverse Ranges may be related to structural complexities and lateral ramps in nearby fault systems. And, the N-S direction of compression seen in the data from the Santa Barbara area is clockwise of the more NE direction reported from adjacent regions.

DYNAMICS OF RUPTURE IN PRESENCE OF GEOMETRICAL COMPLEXITY

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We are investigating the dynamic effects induced by geometrical complexity of the fault zone. Effects studied include heterogeneity of fault strength, bends and stepovers in the fault trace, and the presence of a low-velocity disturbed zone along the fault.

Numerous investigators have found, from inversion of seismic waveforms, that slip rise times are frequently shorter than predicted by simple models of crack dynamics. We find from three-dimensional finite difference simulations that strength heterogeneities on the fault plane can in some cases significantly reduce the average rise time of the slip function. However, the effect on the slip rise time apparently is significant only when there are strength barriers which are too strong to break at all during rupture. Milder forms of strength heterogeneity have limited effect on the slip rise time.

Numerous observations of fault-zone trapped modes have established the existence of a low-velocity zone along fault zones. We use simulations to show that a thick low-

velocity zone can reduce the velocity of rupture, while an lvz limited in thickness to a few tens of meters has little effect on the velocity of rupture. When rupture is localized along the low-velocity zone edge, rupture is accompanied by significant perturbations to the normal stress across the fault.

Numerical Examination of Source Models

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When using the synthetic Green's function to simulate ground motion from large earthquakes, a source model which includes the random nature of the heterogeneities of the complex fault rupture process is required. In this study, we examine composite earthquake models with two different distributions of subevents: one is composed of identical subevents (JB model), and the other had a fractal size distribution (F model). We will provide relations for F model such that the composite source spectrum matches the target spectrum at both low and high frequencies. We also show that by considering the time delays of subevents, the composite source spectrum matches the target source spectrum at intermediate frequencies also.

The synthetic acceleration time histories and corresponding Fourier amplitude spectra are calculated by convolving the composite source time functions with the synthetic Green's functions for M6.7 Northridge earthquake at station Pacoima-Kagel, and for M8.1 Guerrero earthquake at station Caleta de Campos. The subevent stress drop used for Northridge earthquake is 100 bars and 50 bars for Guerrero earthquake. Both composite source models (JB and F) produce realistic seismograms, and the synthetics fit the observations reasonably well.

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be supported by a valid receipt or invoice. This not only helps in tracking expenses but also ensures compliance with tax regulations.

In the second section, the author provides a detailed breakdown of the company's revenue streams. This includes sales from various product lines and services. The data shows a steady increase in revenue over the past year, which is attributed to strategic marketing efforts and product diversification.

The third section focuses on the company's operational costs. It details the expenses related to production, distribution, and administrative functions. The analysis reveals that while production costs have remained relatively stable, distribution costs have increased due to higher fuel prices and logistics challenges.

Finally, the document concludes with a summary of the overall financial performance. It highlights the company's strong profitability and its ability to manage costs effectively. The author also outlines key areas for future improvement, such as optimizing the supply chain and exploring new market opportunities.