Final Technical Report

Submitted to the
U.S. GEOLOGICAL SURVEY

By the Seismological Laboratory
CALIFORNIA INSTITUTE OF TECHNOLOGY

Grant No.:	Award No. 08HQGR0030
Name of Contractor:	California Institute of Technology
Principal Investigator:	Dr. Egill Hauksson Caltech, Seismo Lab; MC 252-21 Pasadena, CA, 91125
Government Technical Officer:	Elizabeth Lemersal External Research Support Manager Earthquake Hazards Program, USGS
Title of Work:	Analysis of Earthquake Data From the Greater Los Angeles Basin and Adjacent Offshore Area, Southern California
Program Objective:	I & III
Effective Date of Contract: Expiration Date:	January 1, 2008 December 31, 2008
Period Covered by report:	1 January 2008 – 31 December 2008
Amount of Contract:	$40,000
Date:	2 March 2009

This work is sponsored by the U.S. Geological Survey under Contract Award No. 08HQGR0030.

Analysis of Earthquake Data from the Greater Los Angeles Basin and Adjacent Offshore Area, Southern California

U.S. Geological Survey Award No. 08HQGR0030

Element I & III

Key words: Geophysics, seismology, seismotectonics

Egill Hauksson

Seismological Laboratory, California Institute of Technology,
Pasadena, CA 91125
Tel.: 626-395 6954
Email: hauksson@gps.caltech.edu
FAX: 626-564 0715

ABSTRACT

We synthesize and interpret local earthquake data recorded by the Caltech/USGS Southern California Seismographic Network (SCSN/CISN) in southern California. The goal is to use the existing regional seismic network data to: (1) refine the regional tectonic framework; (2) investigate the nature and configuration of active surficial and concealed faults; (3) determine spatial and temporal characteristics of regional seismicity; (4) determine the 3D seismic properties of the crust; and (5) delineate potential seismic source zones. Because of the large volume of data and tectonic and geologic complexity of the area, this project is a multi-year effort and has been divided into several tasks.

RESULTS

Preliminary Report on the 29 July 2008 Mw5.4 Chino Hills, Eastern Los Angeles Basin, California, Earthquake Sequence

The 29 July 2008 Mw5.4 Chino Hills earthquake was the largest event to occur within the greater Los Angeles metropolitan region since the Mw6.7 1994 Northridge earthquake. The earthquake was widely felt in a metropolitan region with a population of over 10 million people, and was recorded by hundreds of broadband and strong motion instruments. In this report we present preliminary analysis of the event and discuss its significance within the seismotectonic framework of the northern Los Angeles basin as revealed by previous moderate earthquakes.

The Chino Hills, mainshock-aftershock sequence began at a depth of about 15 km, in the east Los Angeles area at 11:42am (PST) (Figure 1). The epicenter is between two mapped faults: the Whittier fault to the west and the Chino Hills fault to the east. The focal mechanism indicates a mixture of strike-slip and thrust faulting on a west-southwest or a west-northwest striking nodal plane. The mainshock was followed by only two aftershocks with M>3; M3.8 at 11:52 am (PST) and M3.6 at 13:40 pm (PST). In the first two hours, 37 smaller aftershocks were also recorded in the magnitude range of 1.3 to 2.8. By August 14th, the Southern California Seismic Network (SCSN), a joint project of Caltech and USGS had recorded ~150 aftershocks of M≥1.0. The mainshock was not preceded by foreshock activity.

During the 2008 Chino Hills sequence, the SCSN automatically processed real-time waveform data from 370 stations across southern California. The first location and ML magnitude estimate of 5.6 were released ~80 s after the origin time. An updated location and final ML5.8 were released after ~140 s. The automatic moment tensor and the Mw estimate of 5.4 were available ~10 minutes following the origin time. These SCSN rapid notifications were posted on the Web, and data were made available via http://www.data.scec.org and http://earthquake.usgs.gov.

The Chino Hills sequence was widely felt across southern California although damage was minimal. Relatively strong shaking was recorded to the north in the Diamond Bar area and to the northwest in the eastern Los Angeles basin, as demonstrated in the ShakeMap (*Wald et al.*, 1999a) and actual strong motion records, which were made available via http://www.strongmotioncenter.org. The initial ShakeMap, was available 12 minutes after the origin time; six updates of the ShakeMap followed during the next hour as more data arrived from near real-time stations. The final map included amplitudes from 526 California Integrated Seismic Network (CISN) stations. Over 40,000 people filled out an Internet form, "Did You Feel It" to describe the effects of the earthquake at locations throughout southern California.

Five other moderate-sized mainshock-aftershock sequences have occurred in the general vicinity of the Chino Hills earthquake since 1987. The largest event was the Whittier Narrows earthquake of 1 October 1987, which was located about 30 km west-northwest, and had a magnitude of 5.9. It caused 3 direct fatalities, and over $358 million in damage. The Whittier Narrows earthquake resulted from thrust faulting on the Puente Hills thrust (*Shaw and Shearer*, 1999). The other four earthquakes were the M4.6 1989 Montebello, M5.0 1988 Pasadena, M5.2 1990 Upland, and M5.8 1991 Sierra Madre earthquakes. The Montebello earthquake was caused by thrust faulting, similar to the Whittier Narrows mainshock (*Hauksson*, 1990). Both the Pasadena and the Upland earthquakes exhibited west-southwest left lateral strike-slip faulting while the Sierra Madre earthquake exhibited thrust faulting (*Jones et al*., 1990; *Hauksson and Jones*, 1991; *Hauksson*, 1994; *Shearer*, 1997; and *Astiz*, 2000). Thus the crustal deformation associated with the 2008 Chino Hills earthquake is similar to deformation associated with the previous events. For additional information, see *Hauksson et al.* (2008).

Spatial Separation of Large Earthquakes, Aftershocks, and Background Seismicity: Analysis of Interseismic and Coseismic Seismicity Patterns in Southern California

We associate waveform-relocated background seismicity and aftershocks with the 3D shapes of late Quaternary fault zones in southern California. Major earthquakes that can slip more than several meters, aftershocks, and near-fault background seismicity mostly rupture different surfaces within these fault zones. Major earthquakes rupture along the mapped traces of the late Quaternary faults, called the principal slip zones (PSZs). Aftershocks occur either on or in the immediate vicinity of the PSZs, typically within zones that are ±2 km wide. In contrast, the near-fault background seismicity is mostly accommodated on a secondary heterogeneous network of small slip surfaces, and forms spatially decaying distributions extending out to distances of ±10 km away from the PSZs. We call the regions where the enhanced rate of background seismicity occurs, the seismic damage zones. One possible explanation for the presence of the seismic damage zones and associated seismicity is that the damage develops as faults accommodate bends and geometrical irregularities in the PSZs. The seismic damage zones mature and reach their finite width early in the history of a fault, during the first few kilometers of cumulative offset. Alternatively, the similarity in width of seismic damage zones suggests that most fault zones are of almost equal strength, although the amount of cumulative offset varies widely. It may also depend on the strength of the fault zone, the time since the last major earthquake as well as other parameters. In addition, the seismic productivity appears to be influenced by the crustal structure and heat flow, with more extensive fault networks in regions of thin crust and high heat flow.

We have compared the seismicity parameters with the geological parameters of the PSZs (Figure 2). The geological parameters describing each PSZ are the slip rate and the geologic moment rate. The 'slip-rate' multiplied by 'fault area' is equivalent to geologic moment rate, and thus can be considered a proxy for the long-term tectonic strain loading along a particular CFM fault segment.

The seismicity parameters of each of the five PSZ groups are the standard deviation (the half-width of each seismicity distribution clustered around the PSZs), the distance decay, the productivity (derived from the a-value as (10**(a-value -2.0*b-value)/area)) and b-value, which quantifies the relative rate of large and small earthquakes. The productivity is the rate of M≥2 events per area and per year. Other geometrical distribution parameters such as skewness and kurtosis are not easily interpreted and do not exhibit simple relationships with the parameters of the PSZs. The uncertainty in the half-width of seismicity was determined by calculating the difference in the half-width for the full data set and half the data set. Similarly, the uncertainty in the distance decay exponent was determined by removing one data value from the regression calculation at a time. The b-value uncertainty estimate is approximately $b/\sqrt{N}$ for large N where N is number of earthquakes with magnitude larger than the magnitude of completeness (Utsu, 2003). The productivity uncertainty was determined from the b-value uncertainty by estimating the change in productivity from the minimum and maximum b-value slopes.

The seismicity distributions for the five different fault groups have different half-widths and range from 1 km for aftershocks to ~4 km for unconstrained seismicity (Figure 2A). The aftershock-defined and seismicity-defined faults have the narrowest distributions. The fast and slow slip-rate faults along with unconstrained seismicity faults have the broadest distributions. The distance decay rate is more rapid for aftershock-defined faults than for fast and slow slip-rate faults with interseismic seismicity (Figure 2B). Thus aftershocks, and the interseismic background seismicity behave differently. This difference in behavior could be interpreted as being caused by the heterogeneous strain-field in the immediate vicinity of the PSZs which was left behind by the mainshock.

The productivity is much higher for the aftershock-defined and seismicity-defined fault groups (Figure 2C). The fast slip-rate, slow slip-rate, and unconstrained seismicity faults have lower productivity. In part, this result is expected because aftershock sequences are much more productive and constitute more than half of the southern California earthquake catalog. As a group, the high slip-rate faults exhibit the largest b-value (Figure 2D). The low productivity and high b-value of high slip-rate faults is in agreement with the absence of moderate-sized events within their seismic zones. In particular, there is a lack of mainshock-aftershock sequences in the intermediate magnitude range from M5 to M7.

There is an inverse relationship between the half-width of the fault groups and their productivity. The aftershock-defined and seismicity-defined segments have very narrow and high producing distributions. The other three groups of faults that are in essence in their interseismic period have broader distributions with lower productivity. This observation is consistent with the mainshock rupture providing most of the heterogeneous driving strain field for the aftershocks. During the interseismic period all the faults seem to behave in a similar manner.

The characteristic time and space clustering features of aftershock distributions suggest that the background seismicity within the ±10 km wide seismic damage zone is not aftershocks, and is not accommodating seismic slip on the corresponding PSZ. Because the aftershock distributions do not diffuse away from the PSZs and maintain their initial spatial distribution (*Helmstetter et al*., 2003), it is easy to compare their spatial patterns to the background seismicity. Using the half-width versus productivity relations, we can separate the aftershock distributions from the background seismicity distributions. These results for aftershocks are consistent with the clustering models of *Zaliapin et al*. (2007) who showed that aftershocks form a statistically distinct clustered spatial group from background seismicity. For additional information, see Hauksson (2009).

RECENT PUBLICATIONS

Allmann, B. P., P. M. Shearer, and E. Hauksson, Spectral discrimination between quarry blasts and earthquakes in southern California, *Bull. Seismol. Soc. Am.*, 98, 2073-2079, 2008.

Lin, G., P. Shearer, and E. Hauksson, A Search for Temporal Variations in Station Terms in Southern California from 1984 to 2002,,*Bull. Seismol. Soc. of Am.,* 98: 2118 – 2132, 2008.

Hauksson, E., Spatial Separation of Large Earthquakes, Aftershocks, and Background Seismicity: Analysis of Interseismic and Coseismic Seismicity Patterns in Southern California, *Special Frank Evison Issue of PAGEOPH*, *in press*, February 2009.

Hauksson, E., K. Felzer, D. Given, M. Giveon, S. Hough, K. Hutton, H. Kanamori, V. Sevilgen, S. Wei, and A. Yong, Preliminary Report on the 29 July 2008 Mw5.4 Chino Hills, Eastern Los Angeles Basin, California, Earthquake Sequence, *Seismo. Res. Letters*, vol. 79, p. 855- 868, 2008

Hauksson, E., and J. Unruh, Regional tectonics of the Coso geothermal area along the intracontinental plate boundary in central eastern California: Three-dimensional Vp and Vp/Vs models, spatial-temporal seismicity patterns, and seismogenic deformation, *J. Geophys. Res*., 112, B06309, doi:10.1029/2006JB004721, 2007.

Lin G., P. M. Shearer, E. Hauksson, Applying a three-dimensional velocity model, waveform cross correlation, and cluster analysis to locate southern California seismicity from 1981 to 2005, *J. Geophys. Res*., 112, B12309, doi:10.1029/2007JB004986, 2007.

Lin, G., P. M. Shearer, E. Hauksson, and C. H. Thurber, A three-dimensional crustal seismic velocity model for southern California from a composite event method, *J. Geophys. Res*., 112, B11306, doi:10.1029/2007JB004977, 2007.

Plesch, A., J. H. Shaw, C. Benson, W. A .Bryant, S. Carena, M. Cooke, J. Dolan, G. Fuis, E. Gath, L. Grant, E. Hauksson, and others, Community Fault Model (CFM) for Southern California, *Bull. Seismol. Soc. Am.*, 97, 1793-1802, 2007.

Unruh, J., and E. Hauksson, Seismotectonics of an Evolving Intracontinental Plate Boundary, Eastern California*, GSA Special Publication* on the Walker Lane belt, *in press,* 2009.

RECENT REPORTS

Guoqing L. et al., A Preliminary California State-Wide 3D Seismic Velocity Model Using Both Absolute and Differential Times", (abstract), SSA, April, 2008

Giveon M., E. Hauksson, K. Hutton, H. Kanamori, S. Wei, S. E. Hough, K. Felzer, D. Given, V. Sevilgen, and A. Yong (2008), Preliminary Report on the 29 July 2008 MW5.4 Chino Hills, Eastern Los Angeles Basin, California, Earthquake Sequence (poster) presented at the Southern California Earthquake Center, Palm Springs, CA, 2008

Hauksson, E. Applying waveform relocated background seismicity to image late Quaternary fault zones in southern Califorina, (Abstract for Poster) *presented at* 2008 IRIS Workshop, p102, June 2008.

Hauksson, E. (2008), Large Earthquakes, Aftershocks, and Background Seismicity: Analysis of Interseismic and Coseismic Spatial Seismicity Patterns in Southern California (poster) presented at the Southern California Earthquake Center, Palm Springs, CA, 2008

Hauksson, E., Shearer, P., Lin, G., Investigating the Brittle Ductile Transition Zone Using Southern California Seismicity and the SCEC Community Fault Model, *Eos Trans. AGU*, 89(53), Fall Meet. Suppl., Abstract : T51D-03 Meeting in Austria in San Francisco, 2008

Nicholson C., E. Hauksson, A. Plesch, and P. M. Shearer (2008), Resolving 3D Fault Geometry at Depth Along Active Strike-slip Faults: Simple or Complex? (poster) presented at the Southern California Earthquake Center, Palm Springs, CA, 2008

Plesch A., J. H. Shaw, E. Hauksson, and T. Tanimoto (2008), SCEC Community Velocity Model (CVM-H 5.5) (poster) presented at the Southern California Earthquake Center, Palm Springs, CA, 2008

Shao G., C. Ji, and E. Hauksson (2008) Finite Fault Modeling for Moderate-sized Earthquakes (M ~ 5) in Southern California (poster) presented at the Southern California Earthquake Center, Palm Springs, CA, 2008

Shao, G, Ji, C., Hauksson, E., Finite Fault Modeling for Moderate-sized Earthquakes (M~5) in Southern California *Eos Trans. AGU*, 89(53), Fall Meet. Suppl., Abstract S23B-1908 Meeting in Austria in San Francisco, 2008

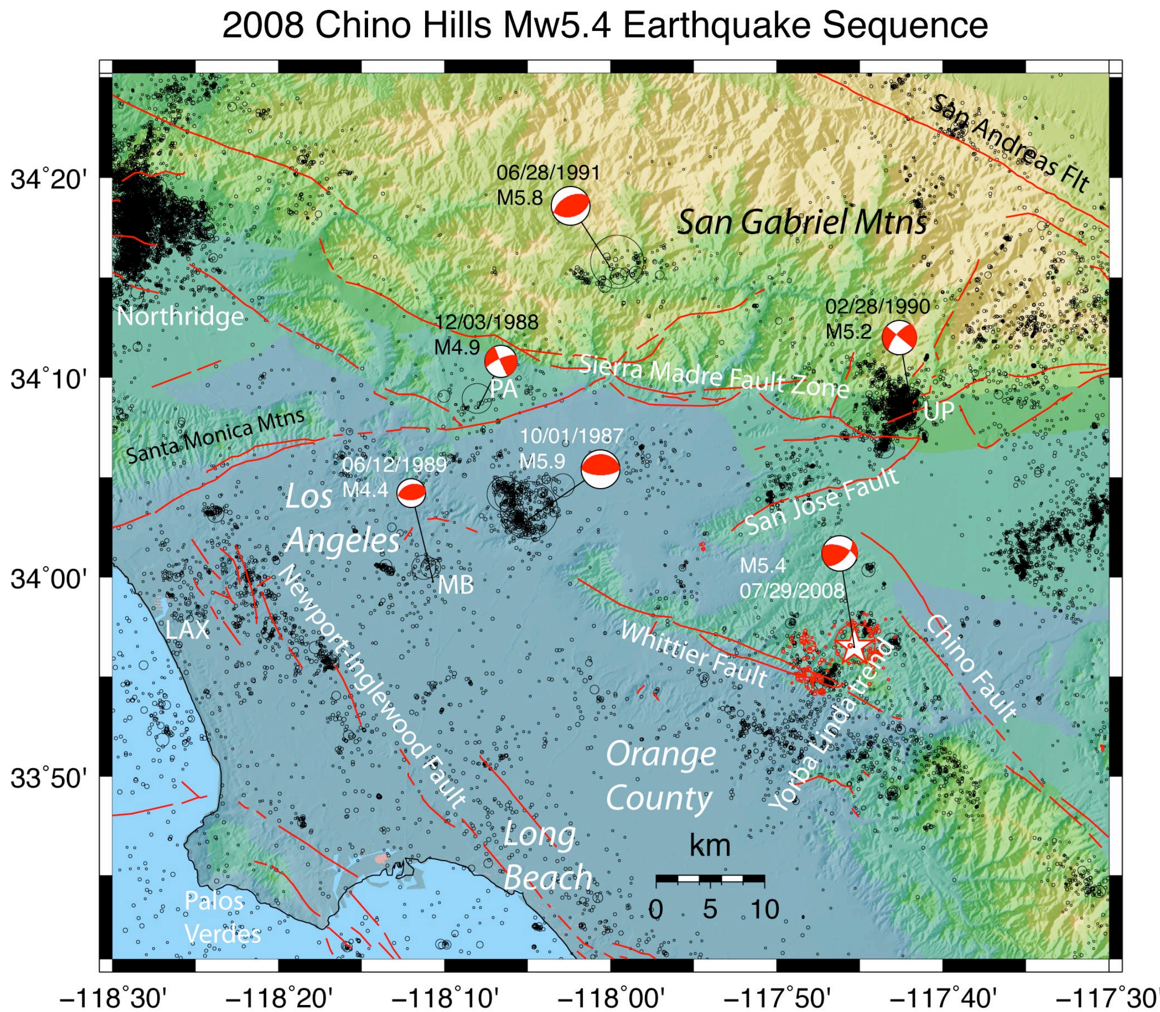

Figure 1. Map of (1981 to 2005) seismicity recorded by the SCSN, and some recent sequences in the Los Angeles Basin, including lower hemisphere focal mechanisms of the moderate-sized mainshocks. The 2008 Chino Hills mainshock is shown as a red star and the aftershocks as red circles. LAX-Los Angeles Airport, MB-Montebello; PA-Pasadena; UP-Upland; WN-Whittier Narrows.

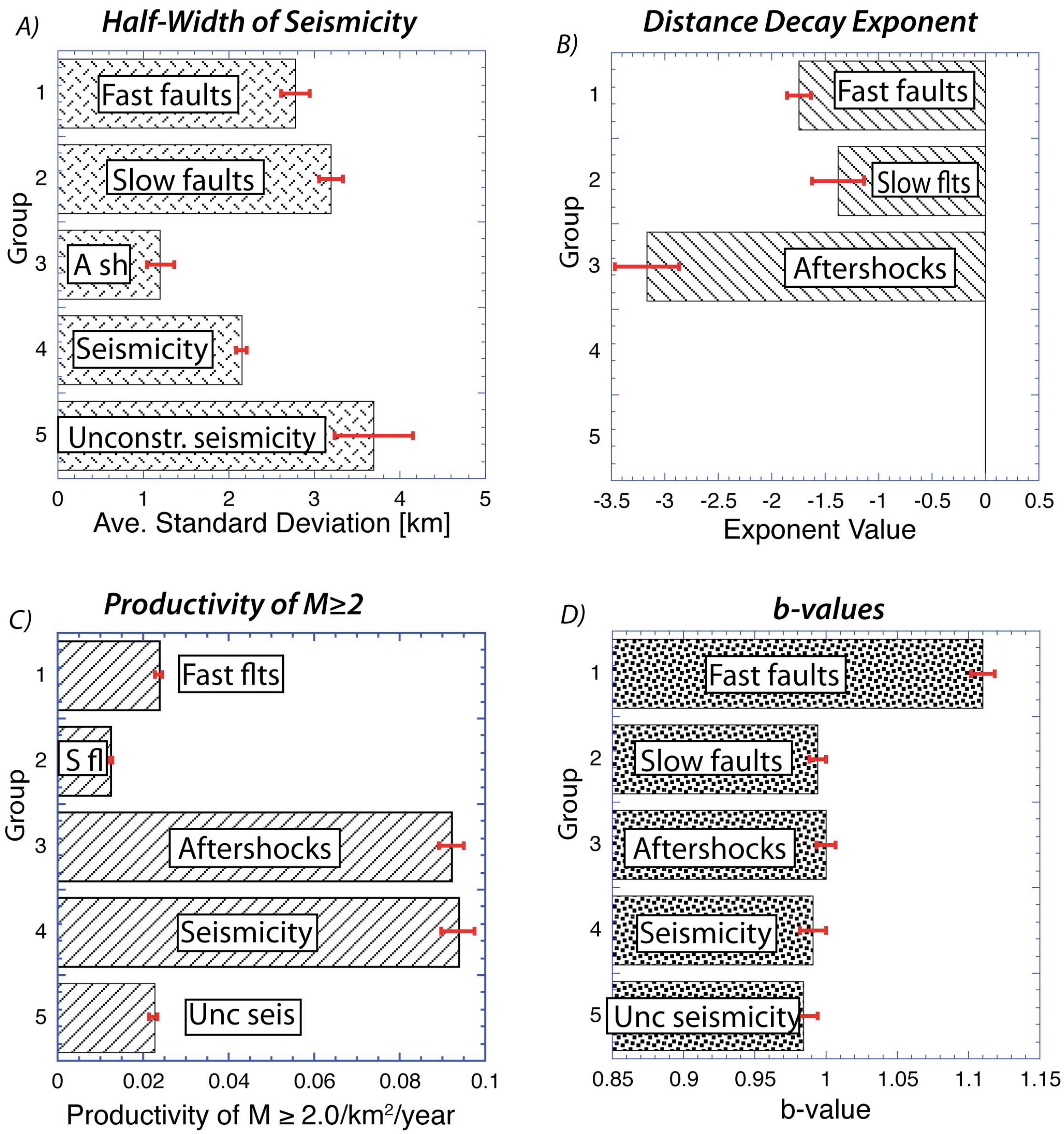

Figure 2. Bar graphs of seismicity parameters for the five fault groups of PSZs. The PSZs are divided into 5 groups as discussed in the text. Error bars of ± one sigma are included. (A) Half-width of the histogram distributions of hypocentral distances; the "half-width" is calculated as the statistical "average deviation" or the statistical width of each histogram; "A sh" – aftershock fault group. (B) Distance decay parameter; this parameter is not available for PSZs that are defined by seismicity or are located near the edges or outside the network reporting area; (C) Seismicity productivity of M≥2.0 per area and year for each of the groups; "s fl" – slow faults group, "Unc seis" unconstrained seismicity fault group; and (D) b-value for each of the groups. "Unc seismicity" unconstrained seismicity fault group.