Final Technical Report

Submitted to the
U.S. GEOLOGICAL SURVEY

By the Seismological Laboratory
CALIFORNIA INSTITUTE OF TECHNOLOGY

Grant No.:	Award No. 07HQGR0048
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, 2007 December 31, 2007
Period Covered by report:	1 January 2007 – 31 December 2007
Amount of Contract:	$61,000
Date:	15 March 2008

This work is sponsored by the U.S. Geological Survey under Contract Award No. 07HQGR0048.

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

U.S. Geological Survey Award No. 07HQGR0048

Element I & III

Key words: Geophysics, seismology, seismotectonics

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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

Quantifying the Correlation of Hypocenters with the Southern California Community Fault Model

We continued to work on this study that was started in 2006. We redid the analysis because a new SCEC Community Fault Model (CFM) 3.0 became available. We also used the latest catalog from Lin et al. (2007). We present a summary of our results below, and plan to complete this study by submitting a manuscript to BSSA or other similar journal.

We apply a Bayesian inference approach to associate hypocenters with individual fault segments of the Southern California Earthquake Center community fault model (SCEC CFM 3.0). We analyzed a waveform relocated earthquake catalog from 1981 to 2005. We have included error estimates using the NonLinLoc method, which provides accurate Bayesian based error ellipsoids. The 3D distances from each hypocenter to the nearest 3D CFM fault segment were determined using GOCAD. On the average, 40% of the background seismicity is located within 2 km distance of the nearest fault (Figure 1). Further, earthquakes with larger magnitudes tend to occur

closer to or on the faults of the CFM model. The San Jacinto fault has the largest association probabilities because of high rate of background seismicity and high slip-rate. In contrast, the San Andreas fault system has smaller association probabilities. This is caused by a lower rate of microseismicity along the San Andreas, and the background seismicity appears to be more distant from the fault trace. We have also extended the method to include geologic slip-rates, as additional prior information for determining a probability for each hypocenter to occur on a CFM fault segment. The a-values associated with each fault do not scale with the tectonic region. The b-values associated with individual fault segments often decrease toward the fault using earthquakes closer to the fault, implying that the large earthquakes are more likely to occur on the mapped faults, with a higher association probability than the smaller ones. These results show that the seismicity distribution adjacent to major late Quaternary faults are similar and thus the fault strength are probably similar.

We use the Gutenberg-Richter law to determine the productivity (a-value) and b-value for each fault segment (Figure 2). Our goal is to search for relations between these parameters and the geological faulting parameters such as fault size, slip rates, or geologic moment rate. If the near-fault background seismicity is strongly influenced by tectonic stress loading there should be some relation between the seismicity and faulting parameters.

We calculated the a-value at magnitude M=0 in the frequency magnitude distribution to determine the productivity of the volume under investigation. We selected magnitude of completeness values (Mc) that are comparable to the results of *Hutton et al*. (2008). We compute the a-value for each fault segment and normalize it to one year. The geographical pattern of fault specific a-values, as shown in Figure 2a, reveals that the most productive faults in the period 1981-2005 are the faults that ruptured during the Landers and Hector Mine earthquakes in the Mojave Desert. Thus the a-values highlight the aftershock sequences following the M7 mainshocks. The 1994 Northridge causative fault is also characterized by a high a-value due to the aftershock sequence. Similarly, the segments of the San Jacinto fault system and the Brawley seismic zone are very active, in part because they sustain a continuous higher rate of background seismicity than being influenced by only one large aftershock sequence.

We use the distance cut-off to compute seismicity parameters and subdivide the earthquakes into different swaths around the faults. The b-value determined for single fault segments vary between 0.45 and 1.8 which is a very broad range, but do not change significantly when moving outward, thus including more events. Although we observe quite a range of b-values in Southern California on different fault segments zones, we do not observe a characteristic or regional pattern.

The four fault segments of the San Jacinto fault zone reveal values of about b=1 on the fault scale, which is slightly higher as the b-values determined on the San Andreas fault segments (Figure 2b). The San Andreas fault has higher b-values to the north on the Cholame segment compared to the more southern Mojave, San Bernardino and Coachella segments, changing from b • 1.1 to b • 1.0. The number of events to compute the b-values is at least one hundred and about 420 for the Mojave and the San Bernardino section, thus considering the uncertainties, the differences are statistically not significant. To the south of the San Andreas fault, the Brawley seismic zones shows again smaller b-values b=0.92. To the west, the Elsinore fault zone segments also reveal values of 0.9, slightly lower than for the San Jacinto fault system.

Seismicity Patterns Within Damage Zones of Principal Slip Surfaces of Southern California Faults

This is a complementary study to the manuscript discussed above. Here we analyze the distribution of the seismicity in the context of average slip rates and geologic moment rates for major faults in southern California. We summarize our results below.

We investigate if the majority of small and large earthquakes occur on the same principal slip surfaces as the major earthquakes that rupture late Quaternary faults in southern California. In most cases, the background seismicity does not identify one or more "slip surfaces" by forming spatially concentrated distributions coinciding with the mapped traces of late Quaternary faults. If some faults were weaker than others, we would expect that the corresponding seismicity distributions would have different forms or degree of clustering. For instance, if the San Andreas fault were exceptionally weak, we would expect that the background seismicity to be concentrated within or close to the weak zone, similar to what is observed along the creeping section of the San Andreas fault in central California.

In rare cases, the relationship between large earthquakes and late Quaternary faults is obvious, when the large earthquake ruptures the surface. If there is no surface rupture, we only have available the location of the hypocenter relative to the fault surface and possibly the focal mechanism to infer the spatial relationship. The background seismicity around the late Quaternary faults, including the San Andreas fault, forms scattered three-dimensional distributions of seismicity extending out to distances of ~(5 to 10) km (Figure 3). We call this distribution of seismicity, the seismic damage zone. One possible explanation for the presence of the seismic damage zone is that it forms as part of the fault to accommodate bends and other geometrical irregularities. The seismic damage zone may form and mature early in the history of a fault, by extending out to approximately ±5 km during the first few kilometers of cumulative offset. As the fault accumulates more slip, the seismic damage zone does not change significantly. However, the rate of seismicity within the seismic damage zone may decrease with cumulative offset and associated smoothing of heterogeneous fault networks. For instance, the San Andreas fault has a factor of ~10 fewer small earthquakes within its seismic damage zone than the San Jacinto fault, which has much less cumulative offset.

In Figures 4a and 4b, we plot the small earthquake productivity of the fault zones and b-value versus average slip-rate. The productivity and b-values are determined from seismicity located within a zone of ±2.0 km width. The slip rates are obtained from the SCEC/USGS Fault Activity Database. For low slip rates (less than 5.0 mm/yr) there is no simple correlation between productivity and b-value, versus slip-rate. In contrast, for high slip-rate faults, such as the San Andreas and San Jacinto faults, there is a negative correlation. Thus, for high slip-rate faults there is less background seismicity and b-values are lower. These observations are consistent with the high slip-rate faults having longer cumulative offsets and less heterogeneity with the seismic damage zone.

If indeed small and major earthquakes rupture mostly different surfaces, the small and major earthquakes may possibly represent independent responses to plate tectonic loading or other loading mechanisms, such as triggering from distant earthquakes. Using a regional catalog thus may not be the best approach to provide a fault specific estimate of strain release or attempting to predict future strain release along the principal slip surfaces of major late Quaternary faults. Another implication is that mapping faults using alignments of small earthquakes may not always help with identifying the principal slip surface.

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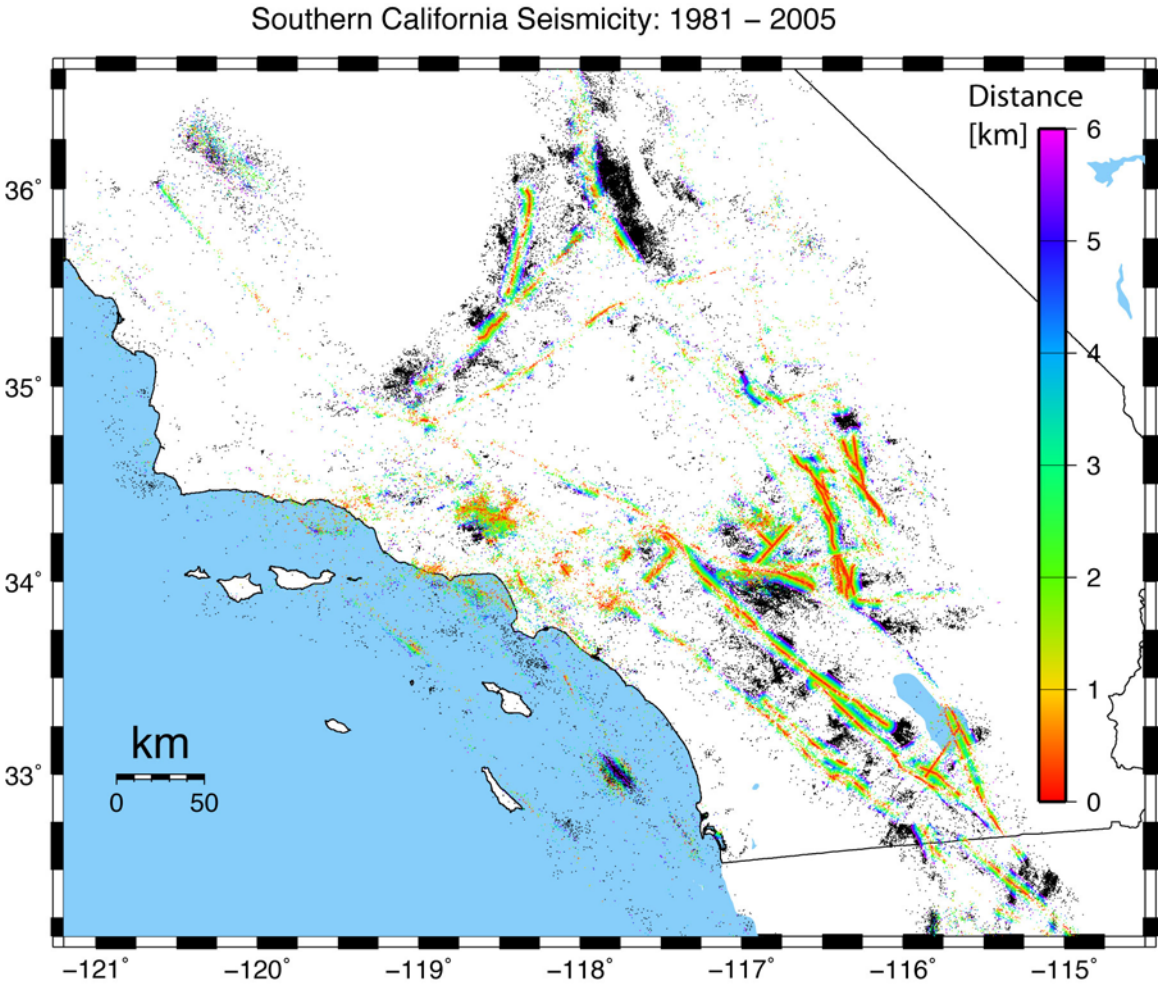

Figure 1. Euclidian distances between hypocenters of the relocated catalog by Lin et al. [2007] and the SCEC CFM v3.0 faults.

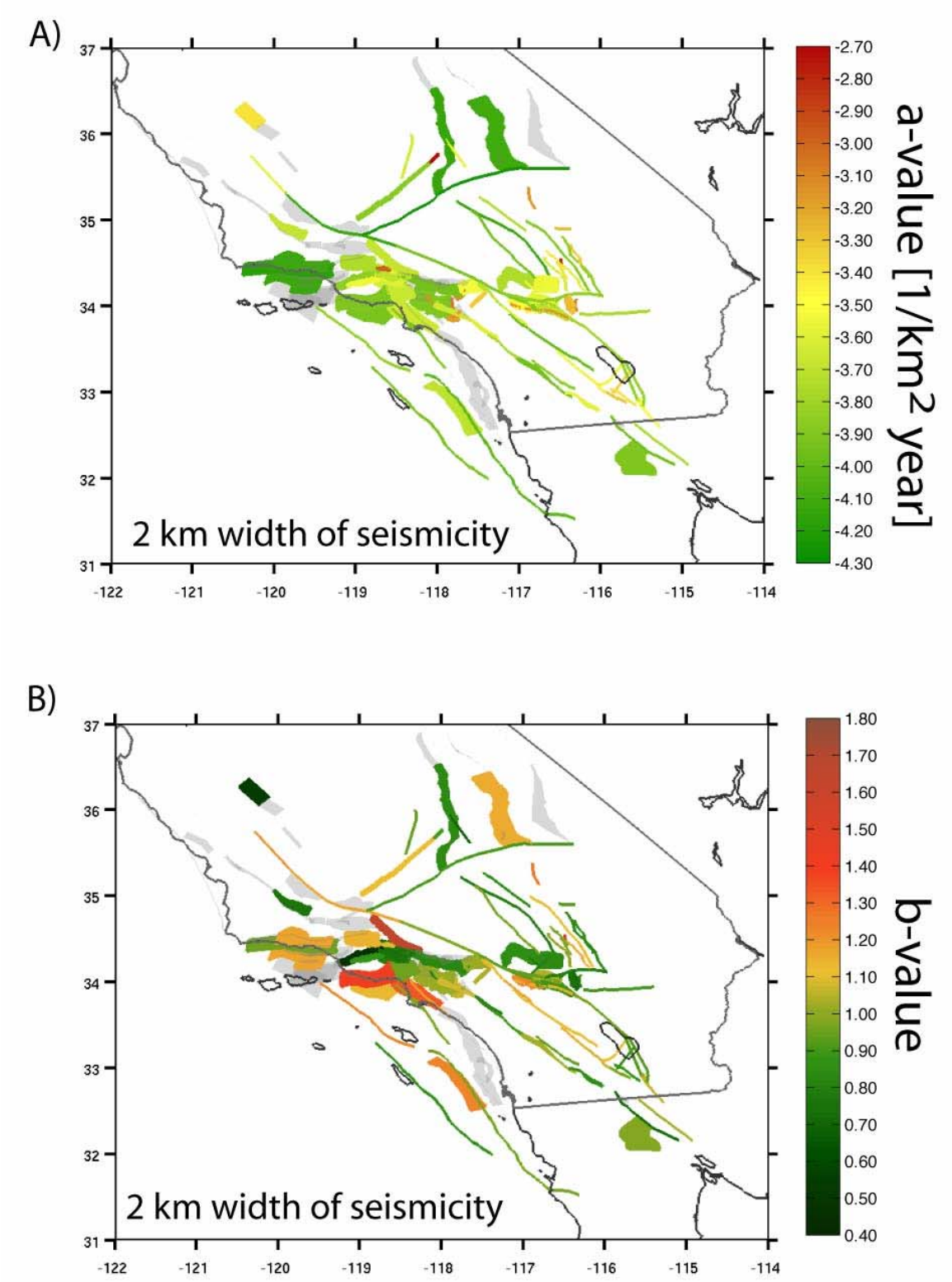

Figure 2 (a) a-values determine from seismicity within 2 km distance of each fault. (b) corresponding b-values.

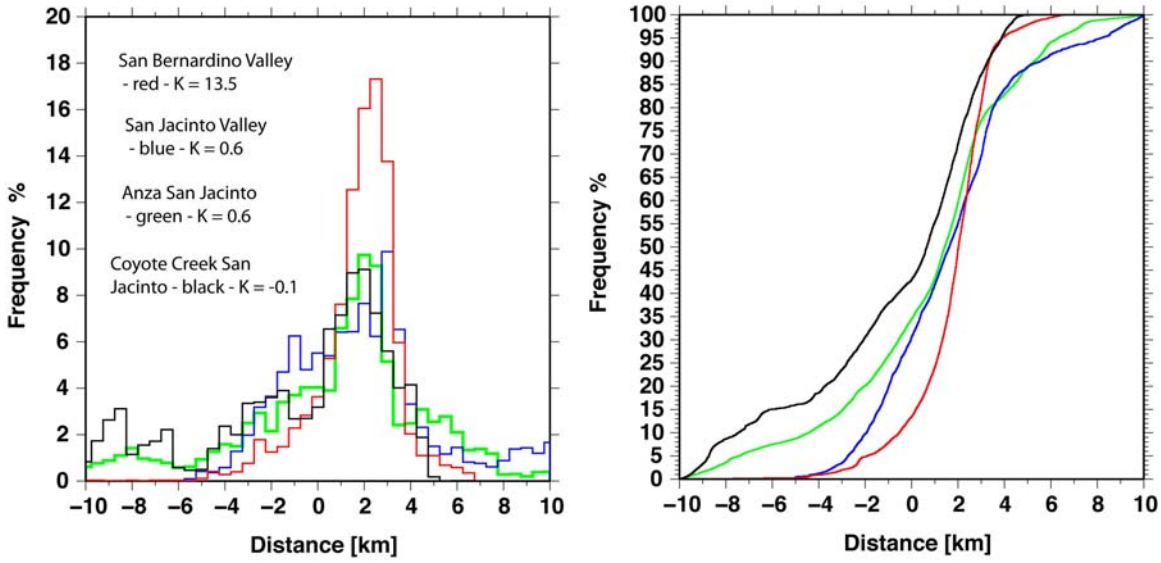

Figure 3. (a) Histograms of seismicity near the fault segments of the San Jacinto fault zone. The kurtosis values for individual segments are also shown. (b) The corresponding cumulative distribution functions corresponding.

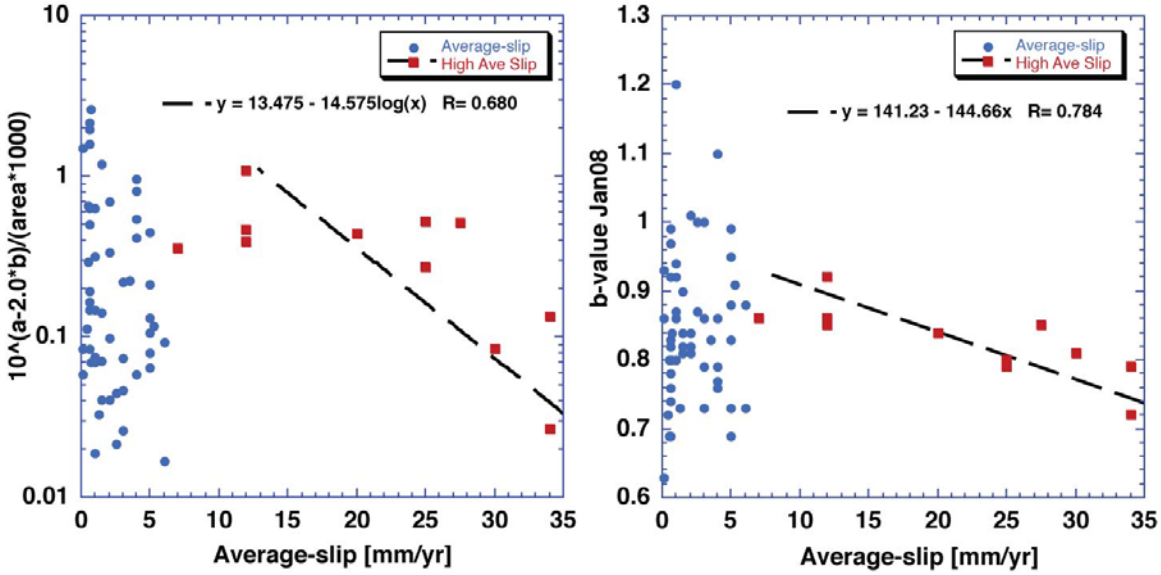

Figure 4. (a) Productivity of M≥2 earthquakes plotted versus geologic moment rate, and (b) corresponding b-values plotted versus geologic moment rate. Selected high-slip rate faults are plotted using separate symbols.