FY2005 Joint UCSD and Caltech Report

Analysis of *P* and *S* Spectra from Southern California Seismograms
for Earthquake Source Properties and Attenuation Structure

Peter M. Shearer
Institute of Geophysics and Planetary Physics
Scripps Institution of Oceanography
U.C. San Diego
La Jolla, CA 92093-0225
pshearer@ucsd.edu

Egill Hauksson
Seismological Laboratory
California Institute of Technology
Pasadena, CA 91125
hauksson@gps.caltech.edu

Introduction

We continued the cooperation between Caltech and UCSD in earthquake seismology research in southern California. The ever-expanding waveform archive of over 400,000 local earthquake records provides an invaluable resource for seismology research that has only begun to be exploited. However, efficiently mining these data requires the development of new analysis methods, an effort that goes beyond the limited resources of individual scientists. We are coordinating these efforts and developing common tools and data products that can be used by us and other researchers to accomplish some of the goals of SCEC.

Our collaboration began with a project to compute waveform cross-correlation times for all 1984–2002 events and to use these times to improve earthquake locations. The first phase of this effort is complete and has yielded dramatic improvements in location accuracy. Our catalogs are available through the SCEC Data Center, and other SCEC researchers have begun to use our locations to study the fine-scale structure of seismicity in southern California. Details about these catalogs are contained in two papers published this year by BSSA (Hauksson and Shearer, 2005a; Shearer et al., 2005a).

During the last year, our SCEC-sponsored research focused on using the online waveform database to compute *P*- and *S*-wave spectra from millions of seismograms from southern California earthquakes. Analysis of these spectra has begun to resolve details in the source characteristics of M = 1 to 3.5 earthquakes as well as lateral variations in crustal attenuation across southern California. We have submitted two papers describing the initial results of this research (Hauksson and Shearer, 2005b; Shearer et al., 2005b).

Stacking spectra to resolve Brune-type stress drops

We have now computed and saved P, S, and noise spectra from over 2 million seismograms from 1984 to 2003. We included all channels and components and resampled the records to a uniform 100 Hz sample rate. We computed *P* spectra from the vertical component and *S* spectra from the transverse component (when available) using a multitaper method applied to a 1.28 s signal window and a pre-arrival noise window. Arrivals were identified using the catalog pick times (when available) or an automatically picked time. We also measured *P*- and *S*-wave peak and RMS amplitudes to use in focal mechanism, directivity, and amplitude attenuation studies. All results are saved in a special binary format that requires about 60 GB of space on our RAID system at Caltech.

Next, we stacked the spectra to isolate source, receiver, and propagation path contributions to the spectra. We have previously used this approach for analysis of global seismic data (*Warren and Shearer,* 2000, 2002). The advantage of the method is that it identifies and removes anomalies that are specific to certain sources or receivers. Because there are difficulties in obtaining reliable and accurate instrument response functions for many of the stations in the archive, this is an important processing step that provides a way to correct for some of these problems.

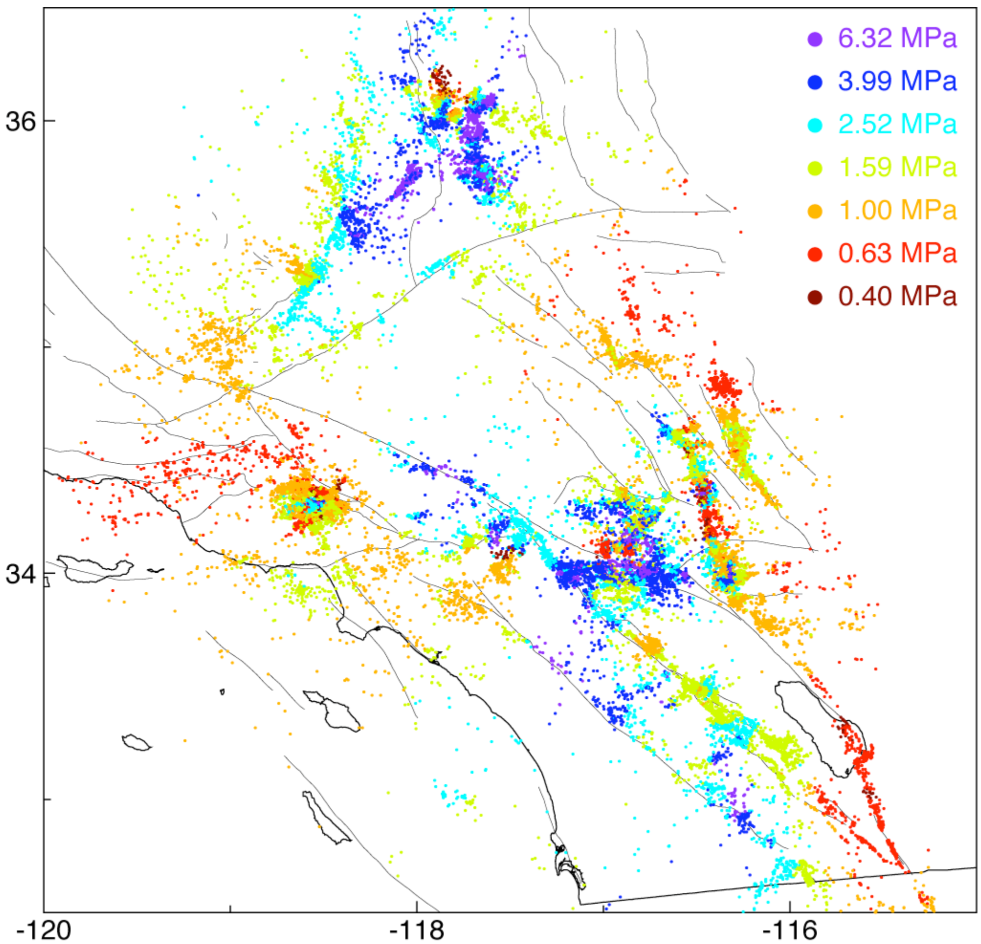

Figure 1. Results of fitting a constant stress drop model to each earthquake and its 500 nearest neighboring earthquakes. Results are colored in equal increments of log $\Delta\sigma$.

We corrected observed source spectra for attenuation using both fixed and spatially varying empirical Green's function methods. Estimated Brune-type stress drops for over 60,000 M = 1.5 to 3.1 earthquakes range from 0.2 to 20 MPa with no dependence on moment or b-value. Median stress drop increases with depth in the upper crust, from about 0.6 MPa at the surface to about 2.2 MPa at 8 km, where it levels off and remains nearly constant in the mid-crust down to about 20 km. Normal fault earthquakes have a higher median stress drop than strike-slip or reverse fault events. Spatially coherent variations in median stress drop are observed, with generally low values for the Imperial Valley and Northridge aftershocks and higher values for the eastern Transverse ranges and the north end of the San Jacinto fault (see Figure 1). We find no correlation between observed stress drop and distance from the San Andreas and other major faults. Significant along-strike variations in stress drop exist for aftershocks of the 1992 Landers earthquake, which may correlate with differences in mainshock slip (see Figure 2).

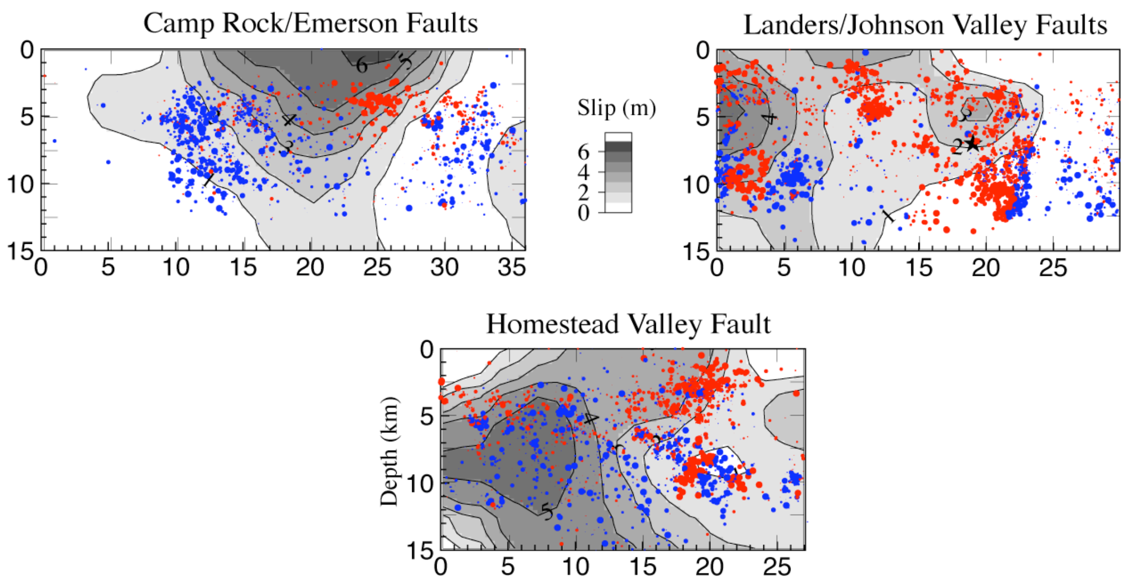

Figure 2. Cross-section of Landers aftershock stress drop estimates compared to the mainshock slip model of Wald and Heaton (1994). Deviations in log Δσ of about 1.48 MPa are scaled by circle size. Relatively low stress drops are plotted in red, relatively high stress drops are plotted in blue. The grayscale contours show slip in meters for the Wald and Heaton model.

3D Qp and Qs Models of Southern California

We have determined 3D Q_P and Q_S models of the southern California crust (Figure 3) using the modified SIMULPS tomographic code for Q determination (courtesy of C. Thurber and D. Eberhart-Phillips, see also Eberhart-Phillips and Chadwick, 2002). These models have generally low Q_P and Q_S (~100) from 0 km down to 4 or 5 km depth, whereas the deeper layers have higher values of $Q_P \sim$ 500–900 and $Q_S \sim$ 600–1000, with a mean Q_S/Q_P = 1.3. The 3D models also image regional variations in Q_P and Q_S that correlate with tectonic structures. Low Q_P and Q_S values exist in the sedimentary basins, such as the Santa Maria, eastern Ventura, Los Angeles, Chino, and San Bernardino basins, and the Salton Trough. Similarly at shallow depth, the most obvious high Q_P and Q_S values are imaged within parts of the batholithic terrains such as the Peninsular Ranges, central Mojave, and southern Sierra Nevada. At mid-crustal depths, imbricate stacking of slightly lower Q values within zones of high Q suggests that such stacking may correspond to areas of high reflectivity, often observed in seismic reflection surveys. There is no obvious correlation with heat flow except for a small area within the Salton Trough, thus suggesting that other factors affect Q more strongly than heat flow. There are no sharp variations in Q_P or Q_S near the brittle-ductile transition, suggesting that the brittle-ductile transition may be a broad zone where the changes in shear or bulk rigidity are only gradual. The station corrections that correspond to the 3D models are related to unknown station calibrations and minor features in the site geology that are not included in the 3D model. In general $Q_S/Q_P > 1$, suggesting dry crust for most of southern California. A few small regions of $Q_S/Q_P < 1$ suggest fluid saturation or larger reductions in shear attenuation rather than in bulk attenuation. In general, the large positive station corrections correspond to stations located on the edges of sedimentary basins, possibly caused by multi-pathing or wave reverberations near the basin edge that are difficult to include in the smoothed 3D models. The negative corrections correspond to regions of very high Q in the near-surface, which, due to the 15 km grid spacing and uneven ray coverage, may not be included in the final 3D model. Further details are provided in Hauksson and Shearer (2005b).

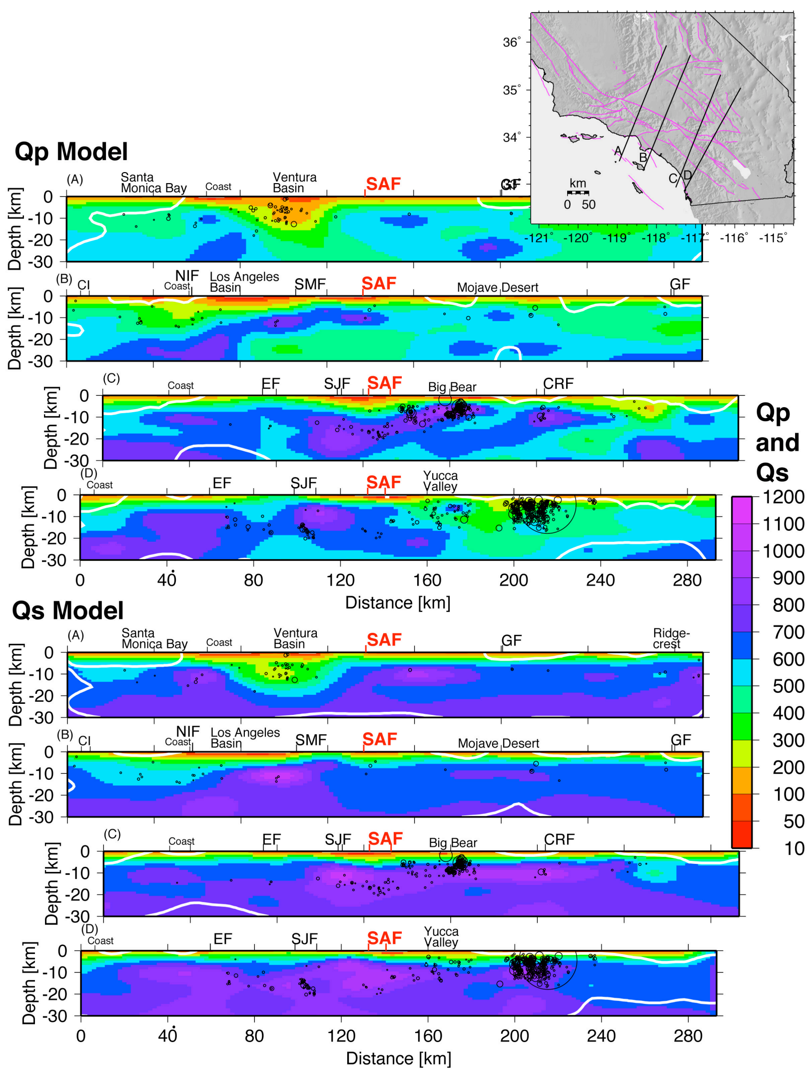

Figure 3. Cross sections through the Q_P and Q_S models extending from southwest to northeast. The map shows locations of the profiles. The white contour lines and the edges of the model outline poorly resolved areas with weighted ray density less than 1000.

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