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3-D Velocity Models, Focal Mechanisms, and Maximum Depth of Seismicity

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The focus of this project is to map the thickness of the seismogenic crust in southern California systematically and quantitatively, using the depth distribution of the background seismicity. We examine the depth distribution of both hypocenters and moment release of the regional seismicity to test which method of earthquake representation is a better predictor of seismogenic thickness. The results of this project will contribute to the understanding of three-dimensional crustal structure, and potentially reduce the uncertainty in seismic hazard models of the region by updating and improving the quality of the fault database parameter, the down dip width.

Comparison of finite source models to pre-mainshock regional seismicity

The first question to be answered is whether background seismicity preceding the mainshock predicts the maximum depth of rupture during the subsequent mainshock. We compare fifteen distinct finite source models for nine moderate to large earthquakes in southern California to the pre-mainshock seismicity of the mainshock region (North Palm Springs, Whittier Narrows, Elmore Ranch, Superstition Hills, Sierra Madre, Joshua Tree, Landers, Northridge, and Hector Mines). The mainshock region is based upon the regional extent of the first 24 hours of aftershocks. We examine depth distribution of both hypocenters and moment release of the regional seismicity to test which method of earthquake representation is a better predictor of seismogenic thickness.

We pose a simple test for the pre-mainshock regional seismicity: What percent of total moment release (Mop) or of total number of hypocenters within the defined region are shallower or equal depth to the bottom of the finite source model in question? This is a simple calculation for earthquake hypocenters because regardless of magnitude, as points in space, the hypocenters can be put in increasing depth order and simply counted. The two-dimensional nature of moment release requires us to sort the moment release of various magnitude earthquakes, and therefore various rupture areas, into depth bins. These depth bins correspond to the depth ranges of the sub-faults that make up a finite source model.

Two potential known errors can affect the moment release depth distribution of background seismicity described above: 1) the potential mislocation in the depth of the hypocenter (vertical error); and 2) the uncertainty in the distribution of the moment release about the hypocenter. These two errors have little effect on the depth distribution of moment release within a region, except if the earthquake contains a significant proportion of the total moment release (Fig. 1). We can see the effect of the errors by considering the extremes in distributing the moment release. We do this by combining the two errors listed above, and looking at the change in the depth distribution of the region. One extreme (Mopmu) shallows the moment distribution by subtracting the vertical error from the hypocenter depth (depth positive) and assuming the earthquake ruptures up from the hypocenter (moment is distributed above the hypocenter). This shallow extreme puts more moment higher in the crust and reduces the maximum depth of seismic rupture. The other extreme (Moppd) deepens the moment distribution by adding the vertical error to the hypocenter depth and assuming the plane ruptures down from the hypocenter (moment is distributed below the hypocenter). Thus, the deep extreme puts more moment deeper in the crust and increases the maximum depth of seismic rupture. Although it is highly unlikely that either extreme of moment distribution with depth actually occurs for all earthquakes within a region, the extremes allow us to place reasonable error bounds on our results.

In the regions of the reference finite source models, the percent of total moment released by the background seismicity above the bottom of the finite source model (Mop) average greater than 99% for 14 of 15 reference models. The exception is the North Palm Springs earthquake, which occurred on the boundary between two regions with maximum earthquake depths that differ by 5 km (Magistrale and Sanders, 1996). On average, the difference between the extremes (Mopmu – Moppd) is about 0.5%, but is often as little as 0.1%. When the variation is greater, the extremes show that the dataset includes one or a few earthquakes that represent a significant proportion of the total moment release of the region are modeled with large uncertainty (usually the uncertainty in proportioning the rupture above and below the hypocenter).

To understand the effect of mainshock region definition on the prediction, we define the 24 hour aftershock zone as loose or tight. This is a simple description of reasonableness when visually identifying the region of aftershocks. The loose aftershock region includes scattered aftershocks as far away as a fault length and the map projection of all the finite source models for that mainshock. Often, the majority of the first 24 hours of aftershocks fall into a compact region surrounding the fault plane, where a tight region can be identified, which excludes some scattered earthquakes farther from the fault. When based solely upon the aftershock distribution, this region can be smaller than the map projection of the finite source models. If this occurs, the tight region is extended to just include the finite source model, where necessary. For earthquakes with multiple models, this may result in the definition of several tight aftershock zones, because the map projection of finite source models can vary from one model to the next.

On average, there is not much difference between loose and tight aftershock zone definitions. The tight definition reduces the number of earthquakes in the region dataset. In the case of the smaller earthquakes (Whittier Narrows and Sierra Madre), the reduction is significant such that the datasets contain less than 10 pre-mainshock earthquakes. Using a larger region can provide more pre-mainshock earthquakes (as the loose definition does for Whittier Narrows), and potentially a more accurate estimate of the seismogenic thickness. The Whittier Narrows and Sierra Madre earthquakes demonstrate the need for caution when considering a region that has a low rate of seismicity. The tight definition also removes some larger (M4 or M5) earthquakes with large uncertainties from the regional seismicity dataset for some comparisons. For the tight region definition, the combination of fewer earthquakes closer to the mainshock rupture plane and less earthquakes with large uncertainty results in a higher average percent (Mop) with a significantly lower standard deviation of the mean. The average percent of moment shallower than the bottom of the reference model increases from 99.2% (– 2.2%) for the loose region definition to 99.8% (–0.5%) for the tight region definition. Using only earthquakes close to the mainshock in the comparison, results in a more stable and consistent predictor. Therefore, we use the value of 99.8% of total moment release when predicting the seismogenic thickness for California.

The values of percent of total number of hypocenters shallower than the bottom of finite source models are more varied than that of moment release. On average, the extreme limits (now based only upon vertical error in the hypocenter depth) vary by about 1%. The variation in the total percent value is also larger than for the moment calculation. The hypocenter depth distribution is easier to calculate than moment distribution, and seems to be reasonably accurate. This technique works fairly well most of the time because only a small number of earthquakes in the dataset have a large enough magnitude to be considered more than a point source within the crust.

Our results show that the moment release distribution is a more accurate and stable predictor of seismogenic thickness than hypocenter distribution, especially when the region considered contains one or more earthquakes in the M4 to M5 range. Therefore, our next step will be to use the depth distribution of moment release for background seismicity to estimate the thickness of the seismogenic crust in southern California.

Predictions of Seismogenic Thickness for the Major Strike-Slip Fault Systems

The three major strike-slip fault systems in southern California contribute a significant proportion of the seismic hazard to the region. Better estimates of the down-dip width of the fault segments should improve the estimation of seismic hazard by improving the estimation of fault area that could rupture during a large earthquake. We have begun to quantitatively estimate the down-dip width of the segments of the San Andreas fault system (Cholame segment and south), the San Jacinto fault system, and the Whittier-Elsinore fault system. We use fault segment definitions of the CDMG database (OFR 96-08). The moment release of seismicity within 10 km of the fault segment is used to calculate the 99.8% depth. We use the extreme distribution of moment release to provide error bars on the depth.

Preliminary results show that the CDMG fault database is over-simplified, and can differ from our estimate of segment down-dip width by more than 2 km. Often, the CDMG database underestimates the down-dip width. The seismogenic thickness also can vary along strike of the segment, and using one value for the entire segment length is inappropriate. This is especially true for the San Jacinto fault system, where the seismogenic thickness systematically shallows to the south.

We plan to provide estimates of seismogenic thickness (with error bars) along the strike of these faults on various scales, from the entire segment to small length-scale variations. Seismogenic thickness estimates for other major southern California faults, as well as thickness estimates on a regional scale are in progress. These estimates should be available within the next two months and will be released to the RELM project leader for the RELM fault database.

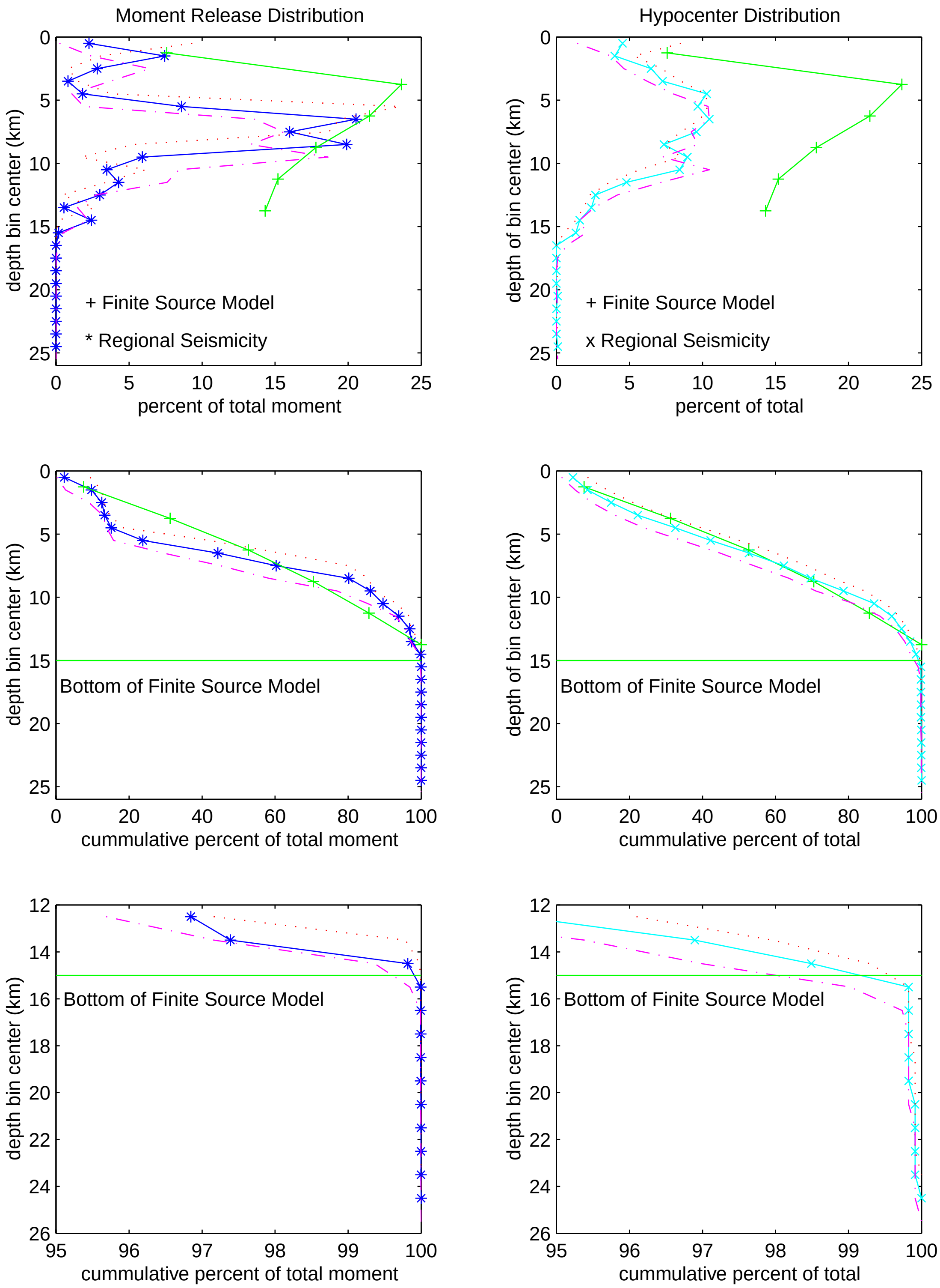

Figure 1. Shows moment release (left column) or hypocenter (right column) depth distribution of regional pre-mainshock seismicity compared to the moment distribution of the finite source reference model for the Landers earthquake. Plotted with * for regional seismicity moment release, x for regional seismicity hypocenters, and + for finite source reference model. The dotted line represents the distribution of moment or hypocenters using the shallow extreme. The dash-dot line represents the deep extreme of moment or hypocenter distribution. First row – depth of bin center vs. percent of total. Second row – depth of bin center vs. cumulative percent of total. Third row – zoom in on cumulative percent at the bottom of the finite source model (15 km). Note that we plot the center of the depth bin for the curves, but the absolute bottom of the finite source model plane with the solid line. Size of depth bin is 1 km for regional seismicity and 2.5 km for the finite source model.