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Thickness of the Seismogenic Crust in Southern California

Julie J. Nazareth and Egill Hauksson
Seismological Laboratory
California Institute of Technology

The focus of this project is to map the thickness of the seismogenic crust in southern California. We define the seismogenic thickness as the depth range between the minimum and maximum depth of seismic rupture. This is the first study that attempts to determine the thickness of the seismogenic crust systematically for southern California, and provide it as one of the independently constrained parameters for seismic hazards analysis. If the seismogenic thickness can be determined accurately, other aspects of hazard models can be improved and possibly the overall uncertainty reduced. In the hazards models the map of seismogenic thickness will be used to infer the depth extent of rupture in future moderate to large scenario earthquakes.

Regional Map of Maximum Depth from Hypocenter Distributions

We have completed a regional map for southern California of the 95% depth of seismicity from 246,000 hypocenters that were calculated using a 3-D velocity model (Hauksson, 2000) (figure 1). The map covers from the Inner California Borderland to the eastern Mojave desert, north to 36 degrees latitude with a portion of the Sierra Nevada and eastern California, and south to the international border with Mexico. Bin size is 0.1 by 0.1 degrees. The maximum depth of seismicity varies significantly across southern California and within fault zones and crustal blocks. The maximum depth is 10-15 km for much of the region, but is significantly deeper in the southwest San Joaquin Valley, Banning Pass-San Gorgonio-San Jacinto Mountains region, between the central Elsinore and San Jacinto fault zones, and in the Ventura Basin. The southern Salton Sea and Brawley Seismic Zone, as well as the central western Mojave Desert have predominantly shallow seismicity.

Similar maps of the depth distribution of hypocenters have been used in the past as an approximation for the depth of faulting. This works well when earthquakes are small because a point source adequately represents the extent of rupture within the crust. As the magnitude of earthquakes increases however, the rupture may extend to shallower and deeper parts of the crust. To establish a correlation between regional seismicity and finite source areas of large earthquakes, we compared the depth distribution of seismic moment and focal depths of regional seismicity, to the moment release distribution of finite source models. This project is ongoing, but we present our preliminary results below.

Comparison of Regional Seismicity and Finite Source Models

In our comparison, we use 17 published finite source models of 8 moderate to large earthquakes that occurred in the last 18 years. These earthquakes have strike-slip, thrust, or oblique mechanisms and include the following earthquakes: 1986 North Palm Springs, 1987 Whittier Narrows, 1987 Elmore Ranch/Superstition Hills sequence, 1991 Sierra Madre, 1992 Joshua Tree, 1992 Landers, 1994 Northridge. Our seismicity data set includes over 246,000 earthquakes recorded between 1981 and 1999 that were relocated with a 3-D velocity model. Errors are less than or equal 2.0 km in the vertical direction and 1.5 km in the horizontal direction. We define regional seismicity to be all earthquakes that occurred before the mainshock, in the region outlined by the first 24 hours of aftershocks. For both the Whittier Narrows and Sierra Madre earthquakes, less than 10 earthquakes occurred in the epicentral region, as defined above, in the 6 to 10 years prior to the mainshock. Results for these earthquakes may not be statistically significant, but they serve to illustrate the challenge of predicting maximum rupture depth for regions with low seismicity rates. To calculate the distribution of seismic moment release with depth, we divide the depth column into bins. We center the fault plane at the earthquake hypocenter and distribute the moment into the depth bins that the plane overlaps.

<u>Seismogneic Thickness Prediction from Seismic Moment</u>

To determine if the regional pre-mainshock seismicity predicts the maximum depth of rupture for the mainshock, we compare the 99.9 % depth (the depth down to which 99.9% of the moment release occurs) of the regional seismicity and the mainshock. This definition allows for a few small earthquakes with small seismic moment to occur at deeper depths, but reasonably encompasses the region in the crust where significant seismic rupture is likely to occur. The choice to use 99.9% is based upon this premise. This approach uses both the seismic moment and the focal depth distribution of the regional seismicity.

The maximum depth of rupture of strike-slip and oblique-slip earthquakes is well predicted, with 7 of 9 finite source models predicting or exceeding the depth of the mainshock fault plane for the North Palm Springs, Elmore Ranch, Superstition Hills, and Landers earthquakes. One finite source model for the Superstition Hills event was underpredicted by 1.1 km (within the depth uncertainty of our hypocenter relocation), but is matched by an exact prediction for a slip model by a different author. The other prediction failure is for the 1992 Joshua Tree event, for which we only have one slip model at this time. The slip model is based solely upon geodetic data which has less depth sensitivity than seismic waveform data, suggesting that the failure of the rupture depth prediction was due to an inappropriate slip model. Other reasons include the nature of the causative fault and the tectonic environment of the earthquake.

The maximum depth of rupture for thrust earthquakes is usually underpredicted by 1.0 to 6.6 km, depending on the slip model used for comparison (6 of 8 models underpredict the depth). Two of the three thrust mainshocks, Whittier Narrows and Sierra Madre, pose a challenge because the maximum depth predictions are based upon so few earthquakes. The six slip models we have for the Northridge event have a wide range in the maximum depth of the mainshock fault plane (14.4 – 25.1 km). Depending on the slip model, we range from over-predicting the maximum depth of rupture by 3.7 km to under-predicting by 6.6 km.

Our preliminary conclusions are that the depth distribution of seismic moment for the regional seismicity is well correlated with the seismic moment release in the mainshocks. Further, both the uncertainty in the depth distribution of the moment release of the mainshocks and the uncertainty in the hypocenters of the regional seismicity contribute to the overall uncertainty in the seismogenic thickness.

<u>Seismogenic Thickness Prediction from Hypocenter Distribution</u>

In this approach we only use the depth distribution of the regional seismicity. We compare the 99.9 % depth (the depth down to which 99.9 % of the hypocenters occur) of the regional seismicity hypocenters and the mainshock moment release distribution of the finite source models used above. The maximum depth of rupture is predicted or over-predicted by the 99% depth of the regional seismicity for all mainshocks except Whittier Narrows and Sierra Madre. The bottom of the slip model fault planes of these two models are located deeper than the deepest pre-mainshock hypocenters.

The maximum depth of rupture is usually over-predicted by the 99.9% depth of hypocenters. The bottom of the rupture plane of the mainshocks occurs at percent depths of 55.8 % to 99.9% (excluding Whittier Narrows and Sierra Madre), with 14 of 15 percent depths located between 93.3% and 99.9%. Using the moment release distribution of regional seismicity, the bottom of the mainshock rupture plane is located between 99.3% to 99.9% for 14 of 15 source models.(49.3% for the 15^{th} model). Hence the use of hypocenters gives a less accurate prediction of the actual bottom of the rupture of the mainshocks than the depth distribution of seismic moment determined from the regional seismicity.

Publications

Hauksson, E., Crustal structure and seismicity distribution adjacent to the Pacific and north America plate boundary in southern California, in press, *J. Geophys. Res.*, 2000.

Nazareth, J.J. and E. Hauksson, Thickness of the Seismogenic Crust in Southern California: Constraints from Seismicity, (abstract), SCEC Annual Meeting, Palm Springs, CA, September 26-29, 1999.

Nazareth, J.J. and E. Hauksson, Thickness of the Seismogenic Crust in Southern California: Constraints from Seismicity, (abstract), Eos, Trans. 80, 714, 1999.

Figure Captions

Figure 1. Regional map of the 95% depth of seismicity in southern California from the locations of hypocenters. The 95% depth is the depth down to which 95% of the earthquake hypocenters occur.

95% Depth from Hypocenters

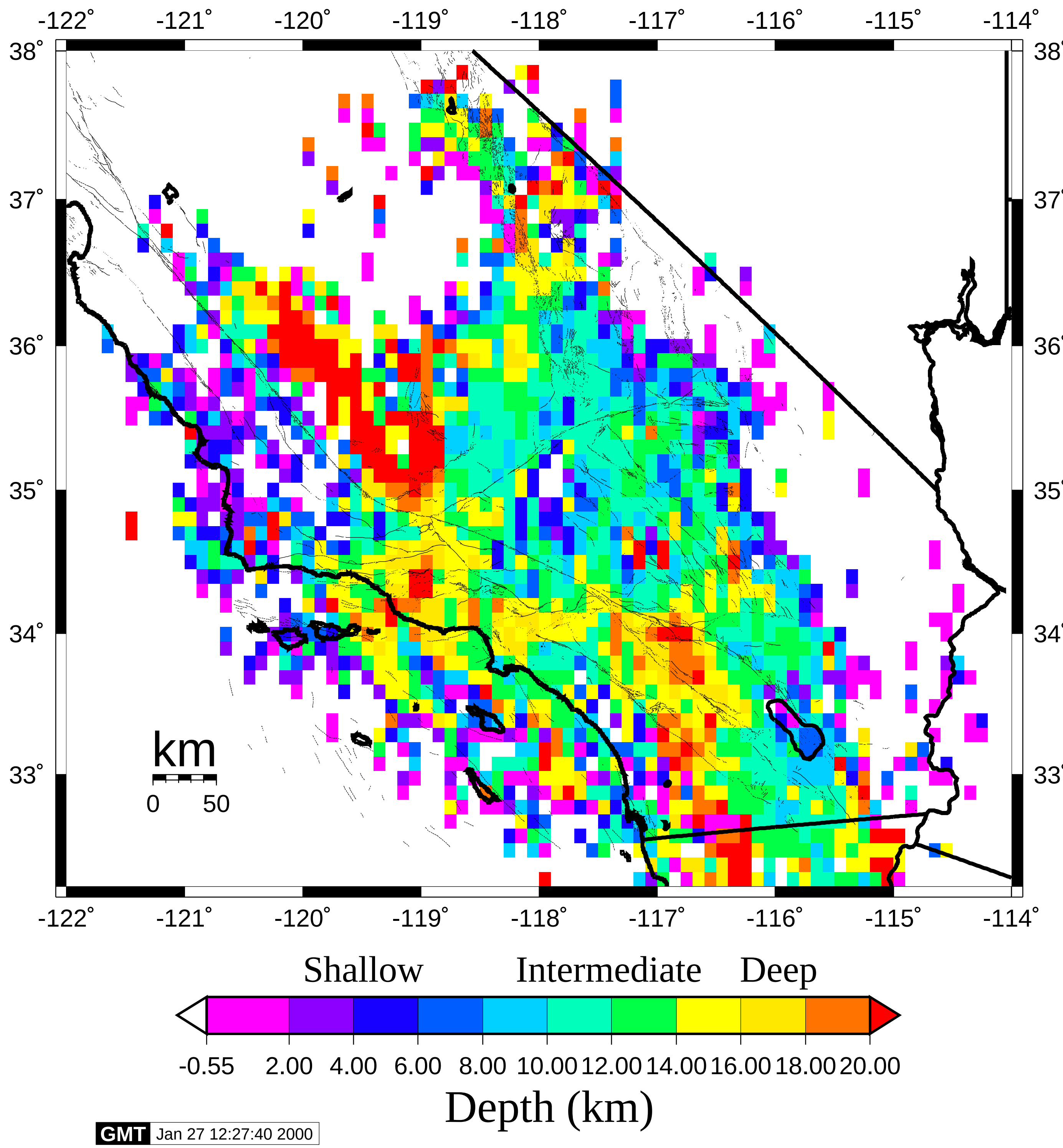

Figure 1