2009 SCEC Report

Characterization of the Wilmington blind-thrust fault for earthquake hazard assessment in metropolitan Los Angeles

Principal Investigator:
John H. Shaw
Professor of Structural & Economic Geology
Harvard University
Dept. of Earth & Planetary Sciences
20 Oxford St., Cambridge, MA 02138
shaw@eps.harvard.edu //(617) 495-8008

Proposal Categories: A: Data gathering and products
Primary Focus Area: CFM
Primary Discipline Group: Geology
Science Objectives: C, A3

Summary
In this study, we define the geometry and slip history of the Wilmington blind-thrust system, which represents one of the largest uncharacterized earthquake source in metropolitan Los Angeles. The blind-thrust underlies the Torrence, Wilmington, and Belmont anticlines, which together extend for more than 40 km along strike across the southwestern Los Angeles basin. Studies have documented recent folding of aquifers above the Wilmington anticline, suggesting that the underlying fault is active (Ehman et al., 2001). Our analysis demonstrates that the fault runs about 30 km along strike, and has a northeast dip of 50-60°NE that shallows with depth. We consider a number of subsurface configurations for the Wilmington thrust in conjunction with other faults in the area. Based on similarities in dip, depth, and ages of activity, we favor a scenario where the Wilmington fault merges with the Compton thrust ramp at depths from 4 to 7 km. Based on its size, we estimate that ruptures of the Wilmington thrust in conjunction with the central segment of the Compton ramp could generate earthquakes of M 6.7 to 7.0 with average recurrence intervals of about 260 to 690 years. Earthquakes that involved other segments of the Compton thrust system would likely be of larger magnitude with longer recurrence intervals.

Wilmington structure
The Wilmington structure is a northwest-trending, doubly plunging anticline that is part of the larger Torrance-Wilmington-Belmont (TWB) trend (Mayuga, 1970; Truex, 1974; Clark, 1978; Wright, 1991; Clarke and Phillips, 2004), which extends about 35 km from the coast at Redondo Beach southeast to offshore Long Beach (Figure 1). The TWB trend comprises a series of structural traps for petroleum fields along the trend. Seismic reflection data from the offshore portion of the structure show that the Wilmington anticline has an asymmetric geometry; the southwestern limb is narrow (1-2 km) and steeply dipping (limb dips of up to 50°), while the northeastern limb is broad and gently dipping (4 km and 20°-25°). Well-imaged syntectonic growth strata on the limbs of this fold indicate that the fold was generated during at least two phases of deformation since the Pliocene. The seismic reflection data also image the reverse offset of the top basement surface on a northeast-dipping blind reverse fault beneath the anticline. Displacement on this fault decreases upward into the core of the fold, which defines the structural trap for the Wilmington oil field. The geometry of the anticline is consistent with it being a tip-line/fault propagation fold (Suppe and Medwedeff, 1990; Erslev, 1991; Hardy and Ford, 1997; Allmendinger, 1998; Shaw et al., 2005) that is generated by displacement on a northeast-dipping blind reverse fault, which we refer to as the Wilmington thrust.

The spatial association of the Compton fault (Shaw and Suppe, 1996) and the Wilmington anticline suggests that the two structures may be linked at depth (Figure 2), and that a portion of the slip on the Compton fault may be transferred onto the Wilmington thrust and consumed in the folding in the anticline. The geometry of the fault, as constrained by seismic and well data, is steeply dipping to the northwest at 50° - 60°. Based on the imaged geometry of the northeast limb of the fold and fault-bend fold theory, we interpret that the fault shallows its dip with depth. Notably, the modeled shape of the Wilmington ramp connects directly with the updip extent of the Compton thrust, which was mapped in previous studies (Shaw and Suppe, 1996; Brankman, 2009). Furthermore, the phases of activity on the Wilmington anticline recorded in the growth strata correspond to similar ages of deformation recorded in the backlimb of the Compton fault. These observations suggest that growth of the Wilmington anticline, and thus slip on the underlying blind fault, are structurally linked to displacement on the Compton fault. Thus, we favor an interpretation where the Wilmington thrust merges with the Compton thrust ramp at depth. The connection between the Wilmington and Compton ramps occurs at depth from 4 to 7 km. Thus, while it is possible that the Wilmington thrust may represent an independent seismic source, we suggest that simultaneous rupture of the linked Wilmington and Compton thrusts poses a greater hazard.

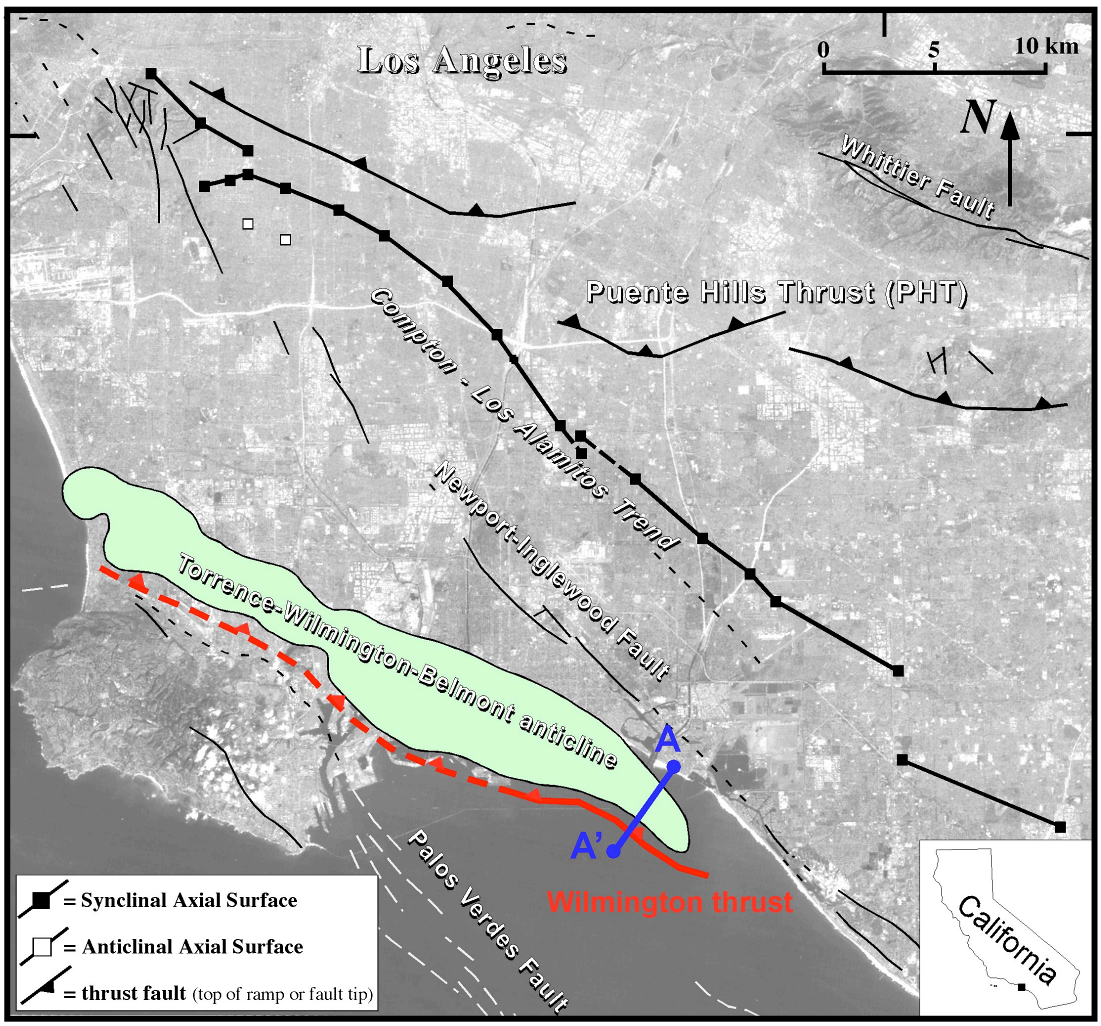

Figure 1: map of the Los Angeles basin showing location of the Torrence – Wilmington-Belmont anticline and the underlying Wilmington blind thrust. Section A-A' is shown in Figure 2.

The total slip on the Wilmington thrust can be estimated by measuring the structural relief on late Pliocene strata between the crest of the Wilmington anticline and adjacent

San Pedro Bay and by estimates of the dip of the fault from kinematic modeling. Based on the top Delmontian surface, which represents a pre-contractional depositional surface, the Wilmington thrust has an estimated total slip of approximately 900 ± 100 m. Restoration of this amount of slip on the thrust shows that the top basement surface had several hundred meters of normal displacement, suggesting that the Wilmington thrust fault is likely a reactivated normal fault that has been inverted as a reverse fault (Truex, 1974; Wright, 1991). Given a maximum slip of about 4 km on the Compton fault, the 1 km of displacement consumed by the Wilmington thrust and fold appear to consume only a portion of the total displacement on the Compton ramp.

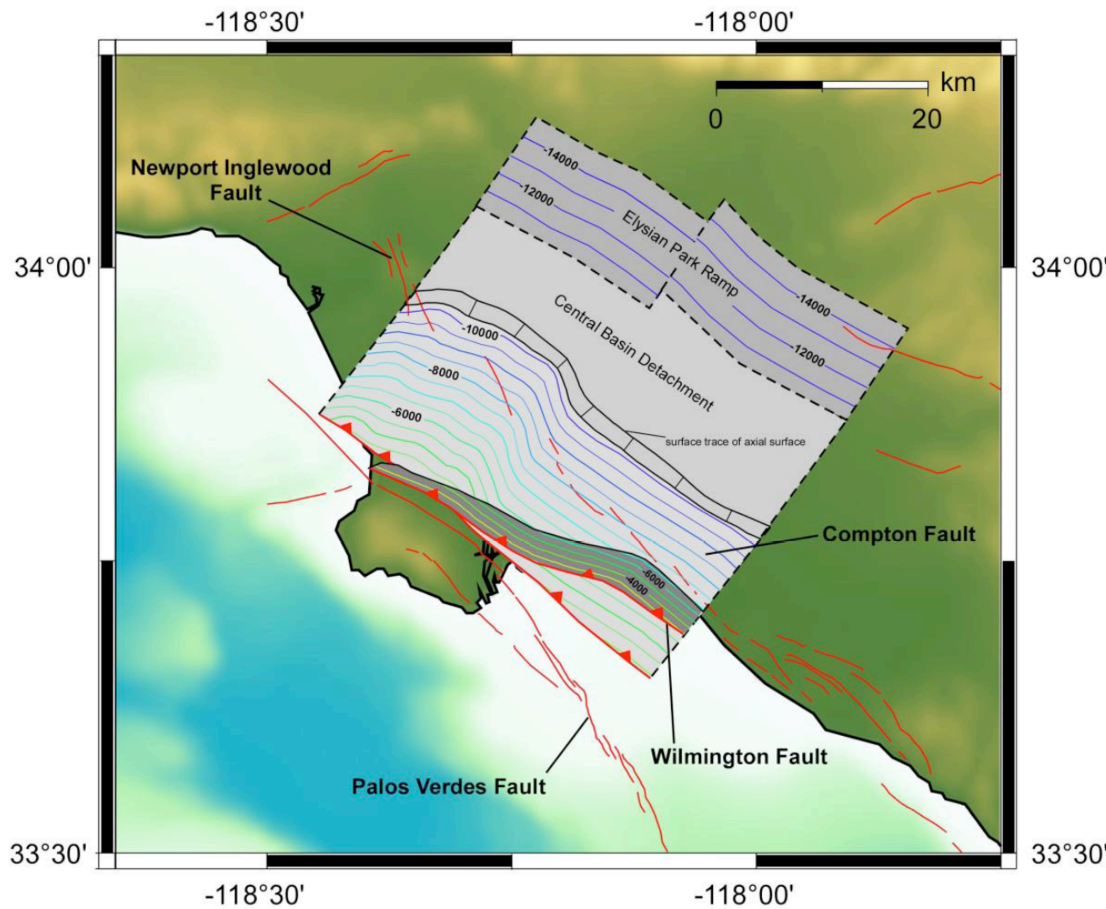

Figure 2: Structure contour map of the Wilmington, Compton, and Elysian Park blind thrust faults. Note that the Wilmington fault and Compton ramp are interpreted to merge at depths from 4 to 7 km.

Seismic hazards assessment

We provide estimates of the magnitudes of potential earthquakes on the linked Wilmington and central Compton faults through empirical relations between fault area and magnitude for thrust and reverse faults (Wells and Coppersmith, 1994). Scenario earthquake magnitudes range from Mw 6.6-7.0 for rupture of these two fault segments. Alternatively, ruptures that also involve other segments of the Compton and Elysian Park thrust system would produce larger earthquakes, up to M 7.4 (Brankman, 2009).

By making the assumption that large earthquakes release the majority of the accumulated moment for the Wilmington and Compton faults, we can calculate the recurrence interval for earthquakes for these rupture scenarios (Shaw and Suppe, 1996). This requires calculation of the average coseismic displacement due to rupture on the fault (Wells and Coppersmith, 1994). We use the long term average slip rate of the southeast and northwest segments of the Compton ramp as conservative bounds in the calculation of recurrence intervals (Brankman, 2009). Using these slip rates, the recurrence intervals for the linked ruptures of the Wilmington and central Compton ramps range from 261-689 yrs, while the recurrence interval for a full multi-segment rupture of the Compton and Wilmington faults and the central basin detachment ranges between 368 – 1014 years.

The estimates for moment magnitude and recurrence interval can be compared with observations from the Holocene geologic record on the central segment of the Compton ramp. Leon et al. (2009) interpreted at least six large (Mw 7.0-7.5) earthquakes during the past 14,000 years on the northwest segment of the Compton fault, resulting in an average recurrence interval of about 2300 years. The recurrence intervals calculated for the Wilmington and central Compton ramps in this study are substantially shorter than the average recurrence interval suggested by the paleoseismic data. This discrepancy suggests that the Wilmington and Compton blind faults may rupture in larger earthquakes, with longer recurrence intervals, in conjunction with other faults located along strike or linked across the central basin detachment.

Results of this study will be incorporated into the SCEC Community Fault Model (CFM) (Plesch et al., 2007).

References

Allmendinger, R., 1998, Inverse and forward numerical modeling of Trishear fault-propagation folds. Tectonics. Vol.17. No.4. 640-656.

Brankman, C., 2009, Three-Dimensional Structure of the Western Los Angeles and Ventura Basins, and Implications for Regional Earthquake Hazards. Ph.D. dissertation, Harvard University, 122 p.

Clarke, Donald D. The structure of the Wilmington oil field. Geologic Field Guide. 1987.

Clarke, D.D., and C.C. Phillips, 2004, Three-dimensional geologic modeling and horizontal drilling bring more oil out of the Wilmington oil field of southern California, in T.R. Carr, E.P. Mason, and C.T. Feazel, eds., Horizontal wells: Focus on the reservoir, AAPG Methods in Exploration, No. 14, p. 27-47.

Erslev, E.A., 1991, Trishear fault-propagation folding, Geology, 19, p.617-620.

Ehman, K.D., D. Ponti, H.E. Clifton, B. D. Edwards, R. J. Fleck, J.W. Hillhouse, S.A. Mahan, K. McDougall, C.L. Powell II, J.C. Tinsley III, 2001, Quaternary stratigraphy and hydrostratigraphy of the Long Beach area, southwest Los Angeles Basin, CA. AAPG Bulletin. Vol. 85. No 6. 1121.

Hardy, S., and M. Ford, 1997, Numerical modeling of trishear fault-propagation folding and associated growth strata, Tectonics, 16, p.841-854.

Leon, L. A., J. F. Dolan, J. H. Shaw, and T. L. Pratt, 2009, Evidence for large Holocene earthquakes on the Compton thrust fault, Los Angeles, California *J. Geophys. Res.,* 114, B12305, doi:10.1029/2008JB006129.

Mayuga, M. N. Geology and development of California's Giant Wilmington oil field. in Geology of Giant Petroleum Fields- Symposium. AAPG Memoir 14. 158-184. 1970.

Plesch, A., J. H. Shaw, C. Benson, W. A. Bryant, S. Carena, M. Cooke, J. Dolan, G. Fuis, E. Gath, L. Grant, E. Hauksson, T. Jordan, M. Kamerling, M. Legg, S. Lindvall, H. Magistrale, C. Nicholson, N. Niemi, M. Oskin, S. Perry, G. Planansky, T. Rockwell, P. Shearer, C. Sorlien, M. P. Süss, J. Suppe, J. Treiman, and R. Yeats, 2007, Community Fault Model (CFM) for Southern California, Bulletin of the Seismological Society of America, Vol. 97, No. 6, doi: 10.1785/012005021

Shaw, J. H., C. Connors, and J. Suppe, 2005, Seismic interpretation of contractional fault-related folds: An AAPG seismic atlas, *American Association of Petroleum Geologists,* Studies in Geology, #53, 157p.

Shaw, J.H., and J. Suppe, 1996, Earthquake hazards of active blind-thrust faults under the central Los Angeles basin, California, Journal of Geophysical Research, 101/B4.

Suppe J. and D. A. Medwedeff, 1990, Geometry and kinematics of fault-propagation folding, Ecolg. Geol. Helv., v. 83, p. 409-454.

Truex, J.N., 1974, Structural evolution of the Wilmington, California, anticline, AAPG Bulletin 58, 2398-2410.

Wells, D.L., and Coppersmith, K.J., 1994, New empirical relationships among the magnitude, rupture length, rupture width, rupture area, and surface displacement, Bulletin of the Seismological Society of America, 84, 974-1002.

Wright, Thomas L. Structural geology and tectonic evolution of the Los Angeles Basin, CA. in Active Margin Basins. AAPG Memoir 52. 1991.