

SCEC 2001 PROPOSAL - GROUP C

1. SYNTHESIS OF ACTIVE EARTHQUAKE SOURCES IN NORTHERN LOS ANGELES BASIN, SANTA MONICA TO SANTA ANA RIVER

2. DISLOCATION MODELING OF BLIND REVERSE FAULTS: SANTA FE SPRINGS

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1. Synthesis of active earthquake sources in northern Los Angeles: We request one month salary for the PI to complete the synthesis of active structures in northern Los Angeles from Santa Monica to the Santa Ana River, to include the Santa Monica, northern Newport-Inglewood, Hollywood, Las Cienegas, Elysian Park-San Vicente, Montebello, Carmenita thrust (Santa Fe Springs), West and East Coyote, Richfield-Kraemer, Whittier, and San Jose faults, and the Puente Hills uplift. Of these structures, the Las Cienegas, Elysian Park, Montebello, Carmenita, West and East Coyote, and Richfield-Kraemer structures are blind, and the structure generating the Puente Hills may be blind also. The goal will be to create a 3D fault map that is available in digital format, and a table of fault attributes including fault length and slip rate. The 3D geology is already done or is being completed with other funding sources, and it is only necessary to organize the fault data in map format and a table of fault attributes. We will work with other members of Group C to achieve a consensus product, and if there are major differences, to display the differences in logic-tree format.

2. Dislocation modeling of blind reverse faults: Santa Fe Springs and West Coyote: With NEHRP funding, Daniel Myers has done dislocation modeling of the West Coyote-East Coyote blind reverse fault, with a constraint on slip rate and maximum magnitude of an earthquake rupturing the entire Coyote source. The West Coyote fold and Hualde dome of East Coyote have similar characteristics and were considered together. Fold amplitude diminishes sharply east of Hualde (Anaheim dome of East Coyote) and west of West Coyote (La Mirada-Leffingwell area). He calibrated the age of the top and base of the Pico member of the Fernando Formation using the Brunhes-Matuyama boundary in the San Pedro Formation between Santa Fe Springs and Montebello anticlines and an ash bed in the Repetto at Santa Fe Springs. The fault has a dip of $60^\circ \pm 10^\circ$ N, and the slip rate is $1.1-1.3 \pm 0.5$ mm/yr. Assuming a stress drop of 100 bars, the moment magnitude is 6 to 7, with a recurrence interval based on the slip rate of 730-1800 yrs.

We request funds for Myers to do dislocation modeling of the Santa Fe Springs blind thrust (Carmenita thrust of industry; Puente Hills thrust of Shaw and Shearer, 1999, *Science* 283:1516-1518). Santa Fe Springs is close to the age control, has an excellent 3D well data set, including preservation of the San Pedro Formation across the fold. The modeled fault generated the 1987 Whittier Narrows earthquake. A dislocation model of the fault can be compared with the fault plane map by Shaw and Shearer (1999) based on fault-plane reflections on a multichannel seismic line, distribution of aftershocks, and a relocation of the mainshock. The slip rate can also be compared with a model of the blind thrust using the trishear method (Allmendinger and Shaw, 2000, *Geology* 28:1099-1102). If time permits, we will also model the Richfield-Kraemer fold to the east.

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Subsurface Synthesis of Northern Los Angeles Basin from the Wilshire Arch to the Whittier Fault

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Introduction

The 1987 Whittier Narrows earthquake (M 5.9) focused attention on blind reverse faults in the northern Los Angeles (LA) basin and led to two models of very large reverse faults with the potential for earthquakes of $M > 7$ in the heavily-populated downtown area. Davis et al. (1989) proposed that the earthquake ruptured part of their Elysian Park blind thrust generating a fault-propagation fold, their Santa Monica Mountains anticlinorium extending from the Puente Hills across northern LA into the Santa Monica Mountains. Shaw and Suppe (1996) proposed a ramp-flat thrust overlain by a fault-bend fold which underlies and controls surface structures extending across the entire LA basin. This structure appears to have been inactive for $> 100,000$ yrs based on trenching along the Compton-Los Alamitos structure and analysis of dated aquifers near the coast by Mueller (1997 and in progress). Near Whittier Narrows itself, the ramp-flat thrust, modeled based on growth sediments, strikes NW, whereas active structures with tectonic-geomorphic expression, such as the Coyote Hills and Montebello Hills, together with the fault-plane solution of the 1987 mainshock, strike east-west. A revised model by Shaw and Shearer (1999) models an east-west blind fault generating the 1987 earthquake called the Puente Hills thrust.

More detailed work delineates several discrete seismogenic structures rather than a single, segmented structure. East of the Newport-Inglewood fault, these are: (1) the Las Cienegas-Los Angeles fault and related Wilshire arch of Schneider et al. (1996) and Tsutsumi et al. (2001), the Elysian Park anticlinorium (EPA) as delineated by Oskin et al. (2000), and the Montebello, Santa Fe Springs, and Coyote folds, related in part to the NW decrease in slip along the Whittier strike-slip fault. Critical to this new appraisal is recent subsurface mapping comparing late Quaternary deformation, an understanding of which drives hazard models, with structures formed during deposition of Pliocene-Pleistocene strata. Late Quaternary structures tend to have topographic evidence of uplift and show evidence of deformation of late Quaternary (post-San Pedro) formations.

This report focuses on progress made under the SCEC award in delineating and documenting active fault sources in the northern LA basin as part of the Legacy Document.

Relation of Hollywood fault to Santa Monica fault

These faults are presumed to be left-lateral, but evidence for Quaternary left slip is equivocal. At the surface, the active strands have a left stepover at their intersection with the Newport-Inglewood right-slip fault. The Hollywood fault is close to the range front east of this intersection but not west, where the active strand (Santa Monica N. strand of Tsutsumi et al., 2001) has stepped out into the basin, creating topography in its hangingwall. The N. strand merges downdip with the low-angle S. strand and may merge with the range-front fault at depth, producing a flower structure. The stepover is marked by the Hollywood pull-apart basin; the bounding Hollywood and North Salt Lake faults and the West Beverly Hills Lineament (WBHL) all have normal separation. (Trenching by Lindvall et al. [2001] shows that the range front may be in part a shoreline angle, and the Hollywood fault is south of a set of normal faults south of the range front.) The intersection at the Newport-Inglewood fault is interpreted as a segment boundary (Tsutsumi et al., 2001).

Las Cienegas and Elysian Park fault sources

The Las Cienegas fault is marked near the surface by a monocline. The slip rate and dip for the blind fault were determined by Schneider et al. (1996) based on Plio-Pleistocene growth strata. Throughout its length, the monocline marks the northern edge of the thick LA trough; both the trough and the Las Cienegas fault terminate westward against the Newport-Inglewood fault. Cores of late Quaternary sediments on both sides of the fault indicate a much slower differential vertical uplift rate for the past 330 ky, 0.09-0.13 mm/yr (Ponti et al., 1996), showing that the Schneider et al. (1996) rate for the past 5 m.y. is not

representative of present earthquake potential. The Las Cienegas fault has its maximum late Quaternary displacement south of the Wilshire arch, where hangingwall uplift is expressed topographically. Farther east, late Quaternary displacement, based on comparing the thickness of the San Pedro Formation (Q on cross sections) on both sides of the structure, dies out. To the north, the Elysian Hills and Monterey Park Hills are uplifted along the active Elysian Park anticline (EPA), with a slip rate of 1.1-1.5 mm/yr on the blind fault based on warped alluvial deposits and the Coyote Pass fold escarpment (Oskin et al., 2000), bending-moment structures at the hinge between the south flank of the anticline and the low-dipping rocks of the hangingwall of the Las Cienegas fault. The Elysian Park blind fault terminates eastward against the East Montebello fault, and it continues westward as the blind San Vicente fault of Schneider et al. (1996).

The late Quaternary slip may transfer eastward from the Las Cienegas fault, active in its western reach, to the Elysian Park fault, most active in its eastern reach. Could the Las Cienegas and Elysian Park faults be stepovers of the same fault at seismogenic depths? If so, the late Quaternary slip rate on the combined structure should be the same or vary monotonically from east to west. But the rate for Las Cienegas is an order of magnitude less than that for Elysian Park, suggesting that the two faults represent separate sources, or that slip is transferring northward from the Las Cienegas to the Elysian Park blind fault.

1987 Whittier Narrows blind thrust:

The mainshock fault-plane solution and the aftershock distribution of the 1987 earthquake (M5.9) are consistent with a north-dipping blind thrust visible as fault-plane reflections on a seismic line (Shaw and Shearer, 1999). Releveling after the earthquake showed that the Santa Fe Springs and Montebello anticlines rose as a single uplift, without accompanying subsidence of the intervening La Habra syncline. San Pedro aquifers mapped by DWR (1961) show no thickening across the La Habra syncline, suggesting that the inactivity of the La Habra syncline between Santa Fe Springs and Whittier Narrows during the 1987 earthquake is typical of long-term behavior.

The blind thrust generating the 1987 earthquake is a separate structure south of the Elysian Park anticlinorium and the Las Cienegas blind fault. The Montebello anticline terminates eastward against the East Montebello right-lateral fault, which may have sustained the largest 1987 aftershock, with a strike-slip fault-plane solution. The Montebello anticline can be generated by the transfer of right slip from the Whittier fault to the Montebello fold. The 1987 aftershocks terminate westward where the Santa Fe Springs and Montebello folds die out, and they terminate eastward where the Santa Fe Springs blind thrust appears to step right to a similar structure at the south edge of the Coyote Hills, discussed below. The 1929 Whittier earthquake, with its north-trending meizoseismals (Richter, 1958), may have occurred on this stepover.

Whittier fault, Coyote folds, and Puente Hills uplift

The Elsinore fault has a right-lateral strike-slip rate of 5-6 mm/yr, but its northwest continuation, the Whittier fault, has a slip rate of only 3 mm/yr in the central Puente Hills and may be much less at the East Montebello fault. The ratio of late Quaternary strike slip to dip slip is about 30 to 1, although the reverse dip separation over several m.y. is several kilometers in the central Puente Hills. The West Coyote and East Coyote anticlines are expressed in uplifted topography. They are bounded by a high-angle reverse fault found in wells on their south flank, a fault that does not deform the San Pedro Formation. This is the South Flank fault in West Coyote field and the Stern fault in East Coyote. Detailed analysis of isopachs of Delmontian and Repettian strata in the Hualde dome of East Coyote field shows that the Stern fault has 1200 m of left slip of strata as young as Repetto. This slip accumulated prior to the end of the Pico and, therefore, prior to folding. A deeper blind fault, beneath well control, generates the topography and deforms the San Pedro into the Coyote fold. The Coyote blind fault may be taking up right slip from the Whittier fault, or it may be a separate structure. The number of folds increases eastward toward the Whittier fault, suggesting a genetic relation.

Dislocation modeling of the Coyote blind fault yields a slip rate of 1.0-1.2 mm/yr (Myers et al., 2000).

At first glance, the Puente Hills are uplifted because they correspond exactly to the restraining bend in the Elsinore-Whittier-East Montebello strike-slip fault system. But this does not explain uplifted topography south of the Whittier fault. Much of the footwall of the Whittier fault consists of an anticline which could explain the uplift of the Whittier fault footwall.

Large vs. moderate-size earthquakes

One view (cf. Shaw and Shearer, 1999) is that the Puente Hills thrust, 1987 Whittier Narrows thrust, Elysian Park anticlinorium, and Santa Monica Mountains blind thrust are all part of a single blind thrust capable of large earthquakes. These thrusts are clearly separate structures; the uplift of the Santa Monica Mountains is considered to be controlled by a north-dipping blind thrust with slip rate of 1 mm/yr or less (Meigs et al., 1999). Even though these four structures can be mapped separately at the surface, they could combine and be a single structure at mainshock depths, or, alternatively, a rupture on one could trigger ruptures on others in a cascade model. So two scenarios are envisioned: (1) faults rupture independently, producing moderate-size earthquakes, or (2) faults rupture together as a single structure at seismogenic depths or as a cascade, producing earthquakes of $M > 7$. A second controlling factor is slip partitioning between strike slip on the Whittier or Santa Monica-Hollywood faults and dip slip on the Puente Hills thrust (footwall anticline) or Santa Monica Mountains thrust.

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An Undergraduate Course in Earthquakes for Non-Majors

I have written a book entitled *Living with Earthquakes in California*, published by the Oregon State University Press. This follows an earlier book, *Living with Earthquakes in the Pacific Northwest* (1998). The book appeared in bookstores in late March, 2001, in time for Earthquake Awareness Month. SCEC Outreach provided partial support for drafting of illustrations and conducting interviews.