Active Deformation and Earthquake Potential of the Southern Los Angeles Basin, Orange County, California

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Investigations Undertaken

The southern Los Angeles (LA) basin has been characterized as moderate to low seismic risk (Petersen and Wesnousky, 1994; WGCEP, 1995). This assessment is based on minimal knowledge of the neotectonics, and may be the result of a gap in knowledge rather than a lack of earthquake sources. Preliminary work suggests that several late Quaternary structures in the southern LA basin have significant rates of deformation but are poorly understood or unrecognized by seismic mitigation professionals and scientists. The earthquake potential posed by these structures is potentially disastrous for the nearly three million people who live and work in Orange County. We are addressing this knowledge gap by building on our recent work in the San Joaquin Hills (Grant et al., 1999; 2000; 2002) and Puente Hills (Gath, 1997; Gath et al., 1992) to identify and analyze other actively deforming structures in the southern LA basin.

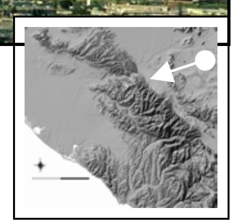

Figure 1. Photograph of Santa Ana Mountains: Standing east of the Santa Ana Mountains (SAM) and looking westward from Riverside, California, notice SAM dominating left portion of the skyline. The Puente Hills (PH) form the low erosion surface to the right of the Santa Ana River (SAR) water gap.

Rising to a height of over 1,700 meters above sea-level, the Santa Ana Mountains (SAM) are the northernmost extent of the California Peninsular Ranges (figure 1) at the southeast margin of the Los Angeles basin (inset, figure 1). They rise nearly 900 meters above the heavily populated urban centers in Orange and Riverside counties, but neither their uplift rate nor uplift mechanism has been determined.

We have been conducting a quantitative tectonic geomorphologic analysis of the Santa Ana Mountains and foothills, including the Peralta Hills and Puente Hills (Figures 1 and 2). The pattern of stream development and channel response is one of the most sensitive indicators of active tectonic deformation. Using standard geomorphic tools and techniques listed in **Table 1**, we are analyzing the fluvial system to determine how active deformation has affected its pattern of development. Much of this analysis is being accomplished with GIS, using a combination of ArcView, Spatial Analyst and RiverTools software processing of 10 m and 30 m DEM data.

Table 1: Tectonic geomorphic analysis methods, southern margin LA basin

• channel length, drainage basin area, and stream power (Hack, 1973; Ohmori, 1993)	• stream channel deflections (Sieh and Jahns, 1984; McGill and Sieh, 1991)
• marine and fluvial terrace morphology (Rockwell et al., 1984; Nicol et al., 1994; Rosenbloom and Anderson, 1994)	• topographic envelope, subenvelope, and residual maps (Bullard and Lettis, 1993; Bürgmann et al., 1994)
• long river profiles (Personius, 1993; Merritts et al., 1994)	• valley asymmetry (Cox 1994) • valley incision (Montgomery, 1994)

During the project period we have also mapped fluvial terraces in the northern SAM and Puente Hills, and contracted with Lewis Owen of UC Riverside for OSL (optically stimulated luminescence) dates. The terrace dating was jointly supported by USGS and SCEC. In 2003 we collected 7 samples from uplifted fluvial terraces along Santiago Creek in the Santa Ana Mountains, and on the north side of the Santa Ana River canyon in the Puente Hills. Preliminary ages of 6 samples are described in this report. One sample was destroyed in a laboratory accident. Collection of additional samples is planned before the project ends.

Results

Geomorphic analysis

Our previous and ongoing work has identified several Quaternary structures that are poorly quantified for seismic risk: the San Joaquin Hills, Puente Hills, Peralta Hills, Loma Ridge, and Santa Ana Mountains. These areas are positive geomorphic features expressing evidence (terraces, wind gaps) of late Quaternary uplift. For our initial analysis, we examined the relationship between drainage basin area and time in the evolutionary development of a fluvial network. This approach has not been widely applied at a regional scale primarily because of the difficulty in providing temporal control for the drainage basins. Our study overcame this difficulty by developing and applying empirical relationships between drainage basin area and age. The relationships were derived in the Puente Hills, where the Whittier fault has a known slip-rate. Next, we determined a relationship between basin area and main-channel age by dividing channel offset by the lateral slip rate of the fault, yielding a formula for basin age as a function of basin area. Finally, we applied this formula for basin age to the Santiago Creek drainage basin in an attempt to determine an approximate emergence age for the SAM. To check the age estimation for Santiago Creek, we also mapped fluvial fill terraces and geomorphic strath surfaces on both the Puente Hills and SAM. These terraces were correlated to the marine eustatic sea level curve used by Grant et al. (1999) for measuring the uplift rate and emergence of the San Joaquin Hills. The drainage basin evolution analysis and terrace correlations yielded emergence age of ~1.2 Ma, and an uplift rate of approximately 0.4 mm/yr for the Puente Hills (Gath et al., 2002). Applying similar methods to the Santa Ana Mountains (work in progress) yields an uplift rate of ~ 0.3 mm/yr.

Age of Terraces for Measurement of uplift

To check the results of geomorphic analysis and terrace age correlations, we are measuring the uplift rates directly by dating the youngest terraces in the Santa Ana Mountains, and on the southern flank of the Puente Hills in Santa Ana River canyon (Figure 2, 3). The Puente Hills have a suite of at least three fill terraces created by the Santa Ana River within Santa Ana Canyon (Gath, 1997). OSL dating of the sediments forming the lowest of these terraces provided an age of 31.9 ± 4.8 ka. This terrace is elevated 27 m above equivalent modern base level of the Santa Ana River, indicating that it, and other higher terraces, have been uplifted since deposition as part of the Puente Hills block. Genesis of the terraces is not readily explained by incision-only models. The preferred model is that these fill terraces were deposited during eustatic sea level high stands, incised by river response to low stands, and preserved by uplift in the intervening low-stands.

At least three similar fill terraces are present on the flank of the Santa Ana Mountains along the north side of Santiago Creek (Figures 2, 4). OSL dating yielded similar sediment ages of 61.4 ± 6.9 ka and 58.5 ± 7.3 ka for two sample locations taken only one meter apart near the base of the first emergent terrace, the surface of which is 27 m above local base level. OSL dating of the sediments near the top of a correlative terrace resulted in an age of 51.5 ± 5.4 ka. Santiago Creek is trapped between the uplifting Santa Ana Mountains and Loma Ridge. Although Santiago Creek would certainly have a response to the eustatic sea level fluctuations, it is likely that tectonic factors are partially responsible for terrace generation and preservation along Santiago Creek.

The Santa Ana River is deflected westerly by growth of the Olive anticline at the westernmost tip of Loma Ridge (Figure 5). This growth is accommodated by the Peralta Hills fault, geomorphically expressed as a 3 meter scarp (fold or fault scarp still uncertain) approximately 100 meters south of the sample location. Two OSL samples were collected from sediments comprising the lowest terrace where the Olive Anticline terminates westerly at the modern river floodplain level. The samples were located 9 to 15 meters above the local Santa Ana River base level. One sample was compromised in a lab accident, and analysis of the second sample indicates an age of at least 75 ka.

When completed and fully analyzed, this new age control will provide valuable constraints on the vertical motion rates of two significant structural blocks in Orange County.

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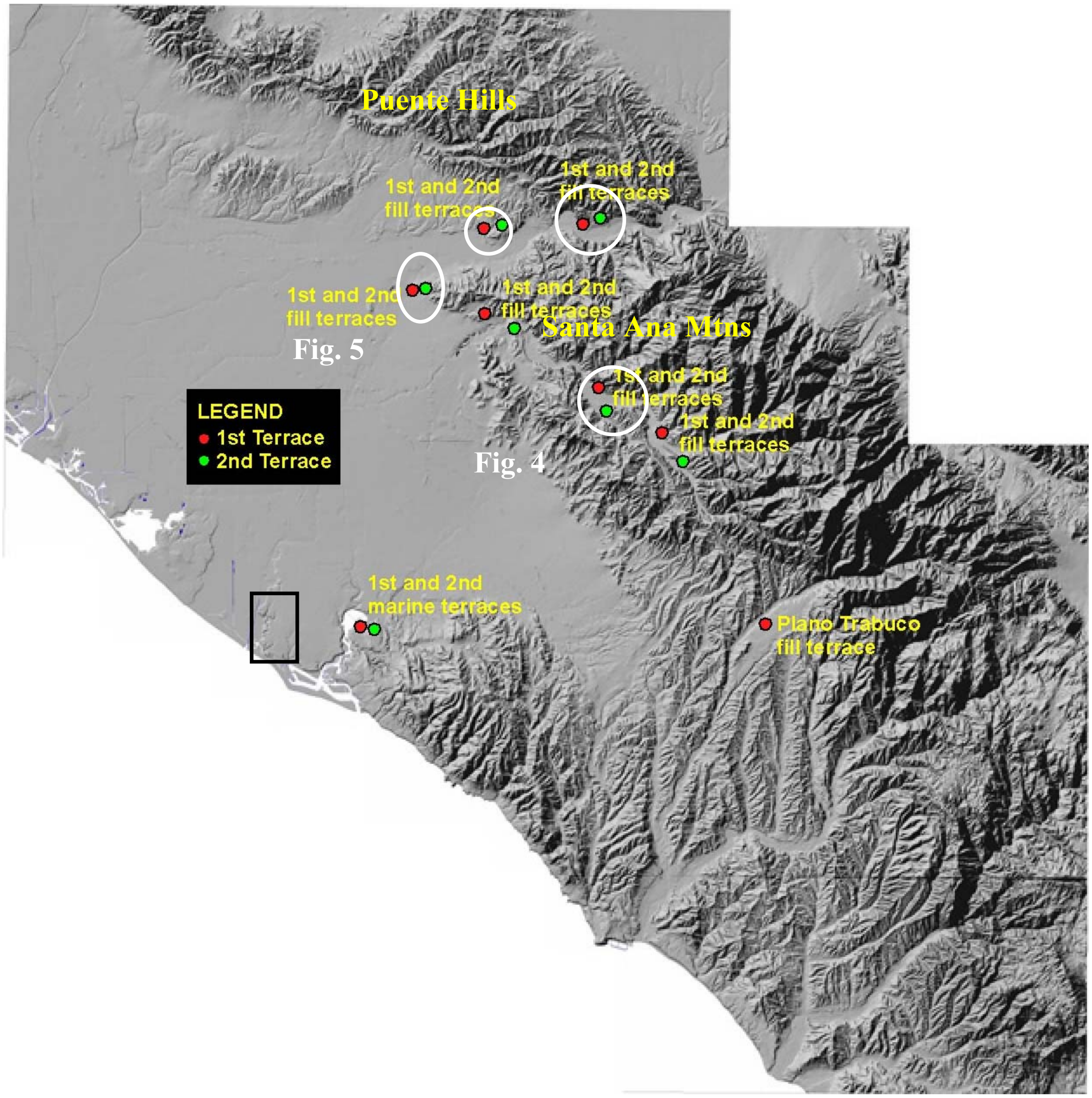

Figure 2: Approximate locations of sampling sites (dots) proposed for this project, and 2003 year-to-date sample locations (enclosed by white circles) for OSL dating in the Santa Ana Mountains and San Joaquin Hills. On closer inspection, proposed sampling sites in the San Joaquin Hills (black box) were eliminated from consideration because they appear to be too old for OSL dating.

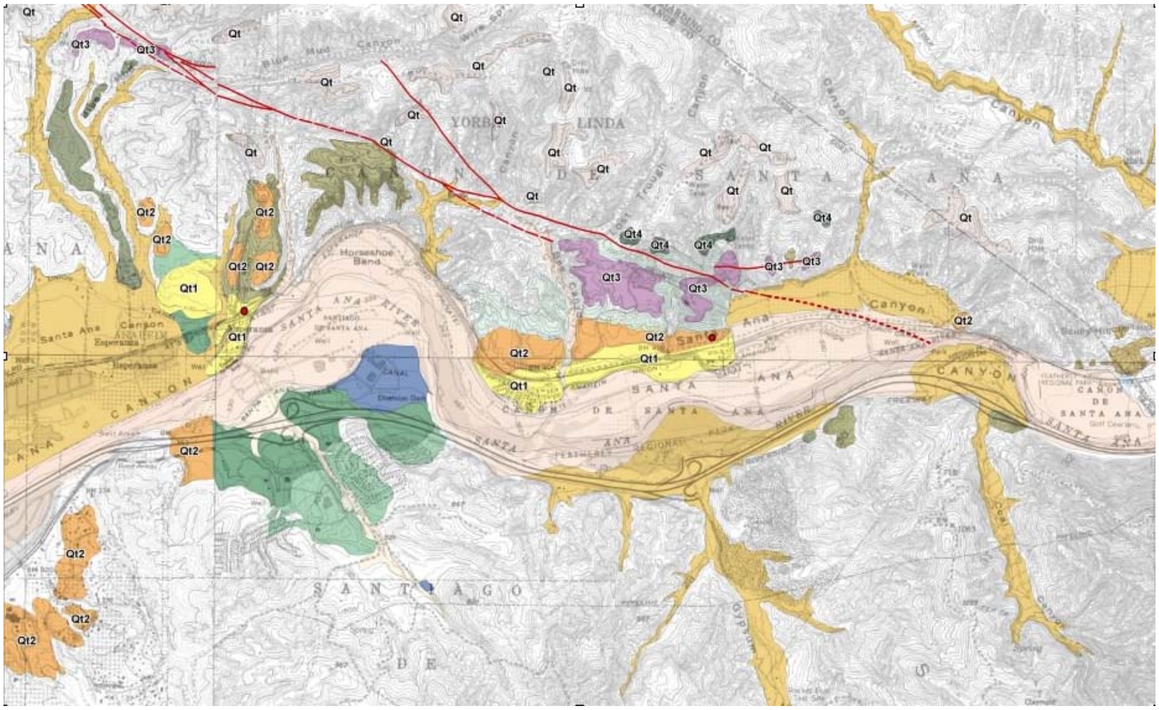

Figure 3 Map of Santa Ana River terraces in Santa Ana Canyon. The Santa Ana River Hills flows between the Puente Hills (to the north) and Santa Ana mountains (to the south). Red dots mark the location of sampling sites for OSL dating on the Puente Hills side of the river. See figure 2 for regional location.

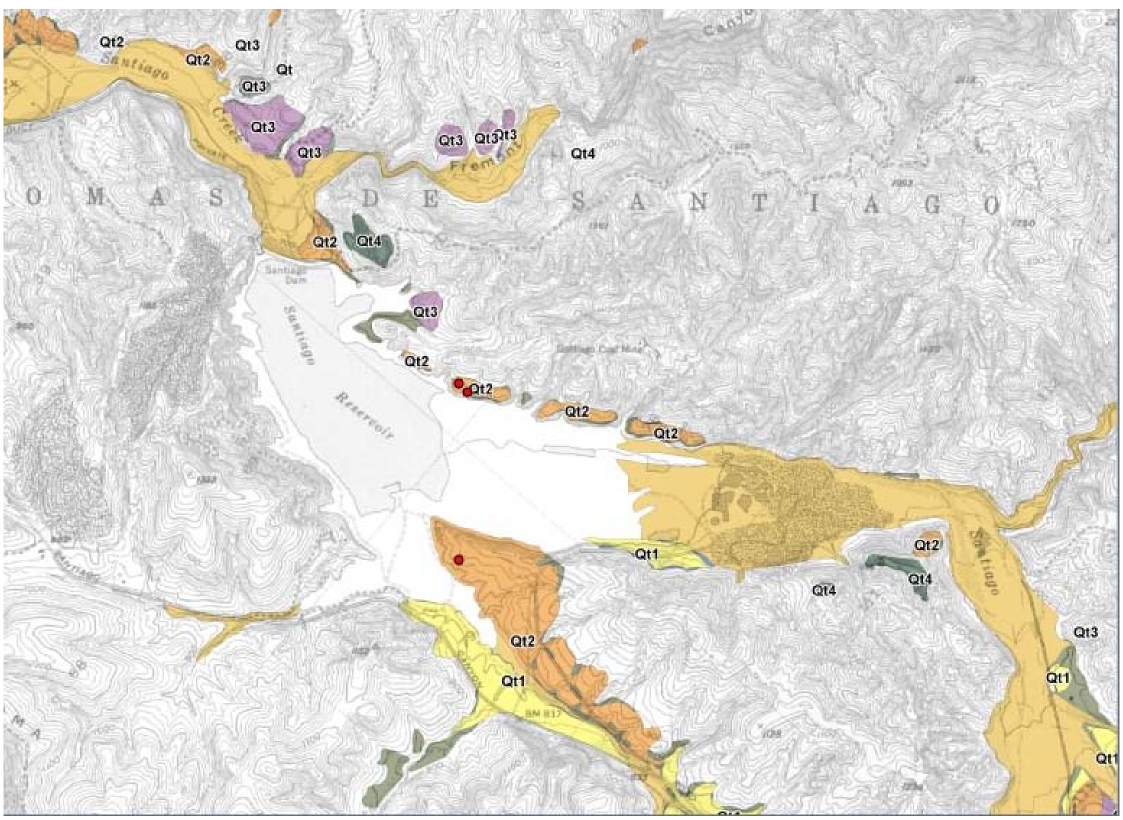

Figure 4 - Map of Santiago Creek terraces at Irvine Lake. See figure 2 for regional location. OSL sampling locations are marked by red dots.

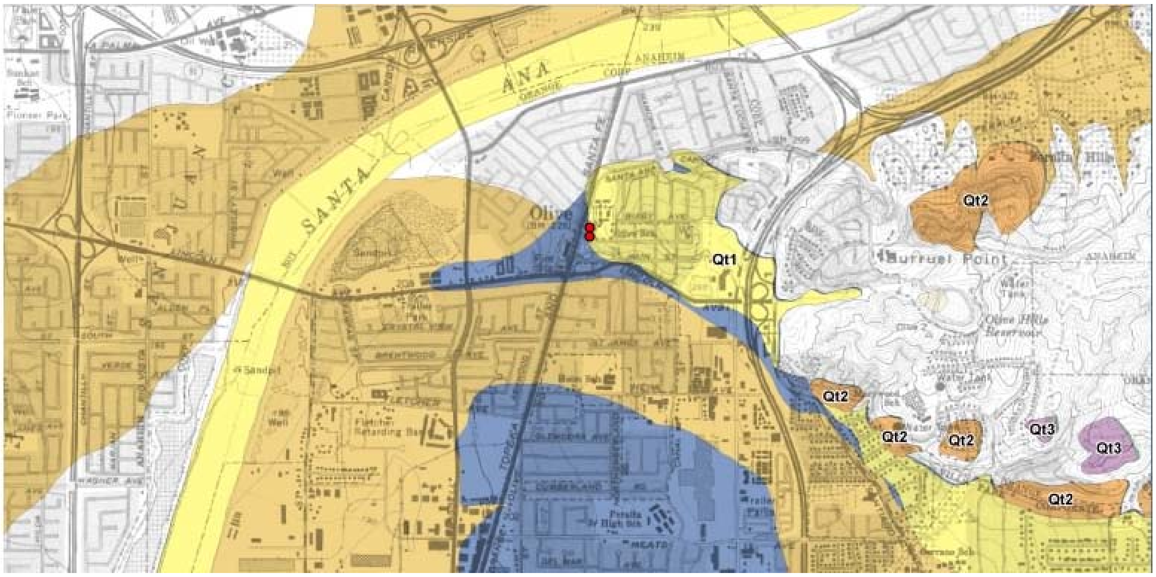

Figure 5 - Map of sampling locations at the westernmost tip of Loma Ridge. See figure 2 for regional location. OSL sampling locations are marked by red dots.

Non-technical summary

The main objective of this research is to better understand seismic hazard in Orange County, California, an area of nearly 3 million people. This project investigates possible tectonic deformation and earthquake potential associated with undiscovered faults in or near the Santa Ana Mountains and Puente Hills by examining the patterns carved by streams. The Santa Ana Mountains are prominent features in the landscape of the metropolitan Los Angeles basin. Comparable sized mountains and foothills in surrounding areas are known to be associated with active faults. Preliminary results indicate that the mountains are rising and may contain active faults.

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Availability of data
Some of the DEM data and geomorphic analysis is posted on the web at http://geolab.seweb.uci.edu/. URLs for private pages with more results can be obtained by contacting project P.I. Lisa Grant (lgrant@uci.edu), or Ph.D. student Eldon Gath (egath@earthconsultants.com). Project data will eventually be archived in Gath's Ph.D. dissertation, which will become available through the UCI libraries.