[PS]Updated Mapping of Active Surface Traces of the San Cayetano Fault Zone between Fillmore and Piru, Ventura Basin, Southern California*

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Abstract

The San Cayetano Fault Zone (SCFZ) is a major east-west-trending north-dipping thrust fault, along the northern edge of the Santa Clara River valley between Upper Ojai Valley and Piru Creek in Ventura County. It is divided into two sections based on a prominent right-step in the fault trace, which forms a lateral ramp along Sespe Creek. At two places in the eastern section, the SCFZ bifurcates into two strands with one located varying distances from the mountain front and another trending higher up through the foothills. One of these splits is found near Fillmore and another near Piru. In each of these cases, it appears the lowermost trace is the active strand, while the upper strand appears inactive. Where the fault exists as a single fault trace near the base of the mountains, it is also active. The California Geological Survey (CGS) recently evaluated the SCFZ in the Piru quadrangle for the Alquist-Priolo Earthquake Fault Zoning program. Here, the "Main strand" continues northeast in the foothills and the "Piru strand" trends more easterly in the alluvium, south of the mountain front. Both strands lose stratigraphic separation and die out east of Piru Creek. Previous geologic mapping in the 1970s through 1990s located the Main strand in the foothills; however, the Piru strand and portions of the Main strand in the alluvium at the base of the mountains are mapped in varying locations, largely inferred from aerial photos and groundwater data. Recently flown Light Detection and Ranging (LiDAR) data and paleoseismic studies allowed for better interpretation of the geomorphic features associated with the SCFZ. These data show the active portions of the SCFZ have discrete geomorphic expression, including prominent south-facing scarps in the alluvium up to 8 m high. In the eastern Fillmore quadrangle, the SCFZ trends nearly north-south as part of the lateral ramp connecting the two primary sections of the fault zone. Here the same pattern is seen with the inactive "Goodenough strand" located in the foothills and the "Main strand" in the alluvium near the mountain front. Recent paleoseismic studies by others, performed east of Fillmore, confirm the lower strand is active. An inactive "upper strand" was mapped during that study, but not as high in the hills as the other two inactive strands to the north and east. In the Fillmore area, scarps are not well preserved due to erosion from Sespe and Pole Creeks, which flow near the base of the mountains.

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UPDATED MAPPING OF ACTIVE SURFACE TRACES OF THE SAN CAYETANO FAULT ZONE BETWEEN FILLMORE AND PIRU, VENTURA BASIN, SOUTHERN CALIFORNIA

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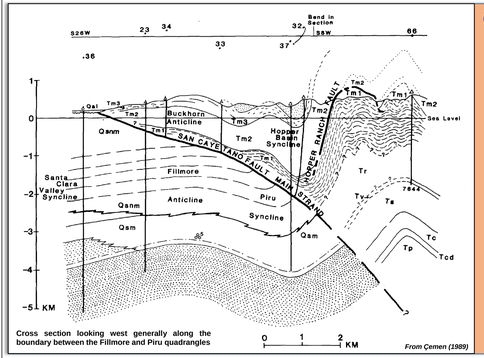
ABSTRACT

The San Cayetano Fault Zone (SCFZ) is a major east-west-trending north-dipping thrust fault, along the northern edge of the Santa Clara River valley between Upper Ojai Valley and Piru Creek in Ventura County. It is divided into two sections based on a prominent right-step in the fault trace, which forms a lateral ramp along Sespe Creek. At two places in the eastern section, the SCFZ bifurcates into two strands with one located varying distances from the mountain front and another trending higher up through the foothills. One of these splits is found in the vicinity of Fillmore and another near Piru. In each of these cases, it appears the lowermost trace is the active strand, while the upper strand appears inactive. Where the fault exists as a single fault trace near the base of the mountains, it is also active.

The California Geological Survey (CGS) recently evaluated the SCFZ in the Piru quadrangle for the Alquist-Priolo Earthquake Fault Zoning program. Here, the "Main strand" continues northeast in the foothills and the "Piru strand" trends more easterly in the alluvium, south of the mountain front. Both strands lose stratigraphic separation and die out east of Piru Creek. Previous geologic mapping in the 1970s through 1990s located the Main strand in the foothills; however, the Piru strand and portions of the Main strand in the alluvium at the base of the mountains are mapped in varying locations, largely inferred from aerial photos and groundwater data. Recently flown Light Detection and Ranging (LiDAR) data and paleoseismic studies allowed for better interpretation of the geomorphic features associated with the SCFZ. These data show the active portions of the SCFZ have discrete geomorphic expression, including prominent south-facing scarps in the alluvium up to 8 m high.

In the eastern Fillmore quadrangle, the SCFZ trends nearly north-south as part of the lateral ramp connecting the two primary sections of the fault zone. Here the same pattern is seen with the inactive "Goodenough strand" located in the foothills and the "Main strand" in the alluvium near the mountain front. Recent paleoseismic studies by others, performed east of Fillmore, confirm the lower strand is active. An inactive "upper strand" was mapped during that study, but not as high in the hills as the other two inactive strands to the north and east. In the Fillmore area scarps are not well preserved due to erosion from Sespe and Pole Creeks, which flow near the base of the mountains.



Cross section looking west generally along the boundary between the Fillmore and Piru quadrangles

From Çemen (1989)

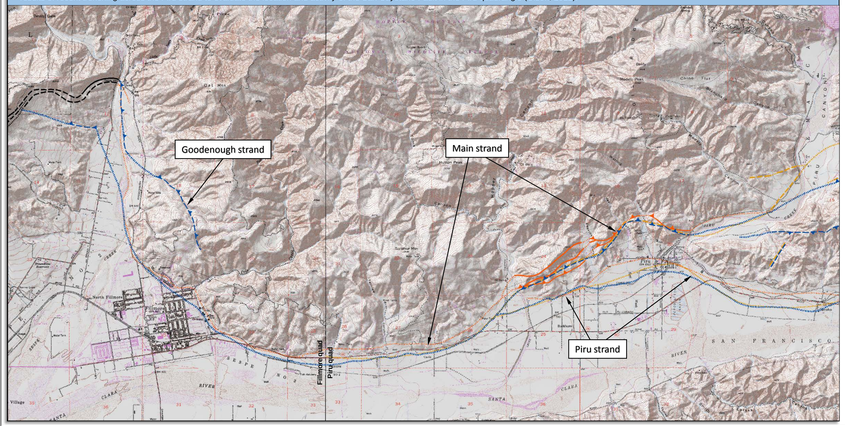
A REGIONAL TECTONIC SETTING

The study area is located in the southwest portion of the Transverse Ranges geomorphic province. In this area, deformation is dominated by roughly east-west trending low-angle reverse faulting and folding driven by north-south tectonic compression. Bedrock in the southern foothills is dominated by the Miocene Modelo Formation, Pliocene Fernando Formation and Plio-Pleistocene Saugus Formation, which are faulted and folded in a series of anticlines and synclines whose fold axes generally trend east-west. The Modelo Formation (Tm) consists mainly of sandstone and shale, while the Fernando Formation (Pico Member) is composed chiefly of marine siltstone. The Saugus Formation is informally divided into two members: a lower marine member composed of conglomerate and silty sandstone with minor siltstone beds and a non-marine upper member consisting of chiefly massive sandstone and pebble conglomerate. Late Quaternary alluvium is mapped in the Santa Clara River and Piru Creek alluvial valleys and as coalescing alluvial fans emanating from the various north-south trending canyons in the mountains north of the Santa Clara River valley.

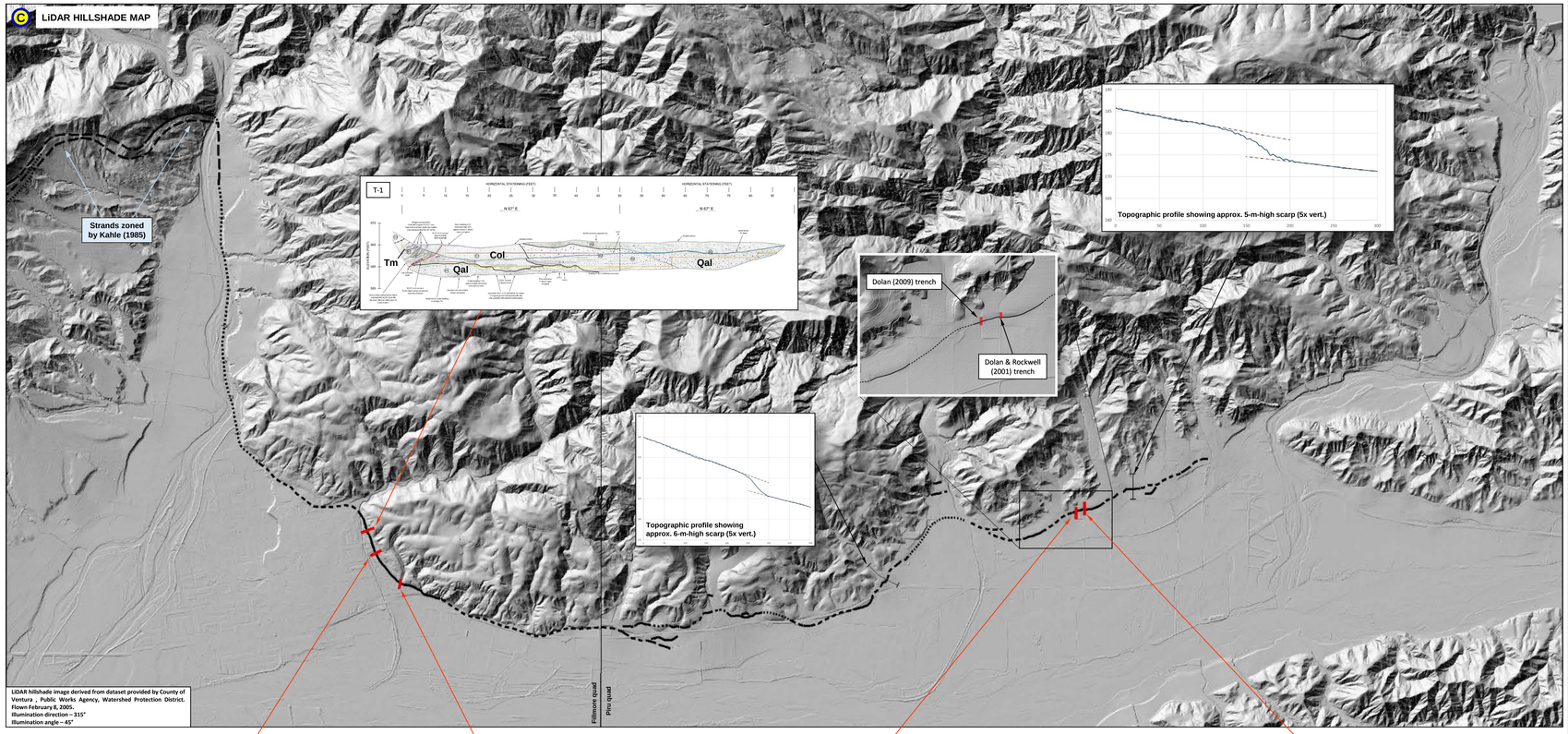
The San Cayetano Fault is characterized as a thrust fault due to the relatively low dip angles and reverse separation of stratigraphic units. Based on geologic mapping and well data, workers indicate the fault plane dips at a very low angle in the shallow subsurface (10°-30°) and becomes gradually steeper with depth. Cumulative dip-slip displacement on the San Cayetano Fault has proven difficult to determine because the oldest units in the hanging wall have yet to be encountered in any wells drilled to date in the footwall of the fault; however, Rockwell (1988) and Çemen (1989) both calculate approximately 7,500 meters of total stratigraphic separation on the eastern segment of the fault using the maximum thickness of the bedrock units in both the hanging wall and footwall. Separation decreases notably to the east on both strands, such that it is completely lost as it transitions into the East Ventura fold belt (Huftile and Yeats, 1995). Quaternary slip rates for the Modelo lobe of the fault range from 7.3 to 7.5 mm/yr (Rockwell, 1988; Çemen, 1989; Huftile and Yeats, 1996), which is significantly higher than rates calculated for the western portion of approximately 1 to 3.6 mm/yr (Rockwell, 1988). Dolan and Rockwell (2001) note this is one of the highest slip rates of any reverse fault known in California.

B PREVIOUS FAULT MAPPING

The easternmost portion of the San Cayetano Fault is mapped mainly in the foothills along the southern flank of the mountains and in the alluvium near the base of the hills. Since the 1950s geologist have focused on this area due to the valuable petroleum reserves that are found in the Ventura Basin. Several workers, including Çemen (1977), Dibblee (1991), and Yerkes (1995), have mapped the surface trace of the San Cayetano. The fault is divided into two major sections based on a prominent 4 km right-step in the fault trace forming a lateral ramp at Sespe Creek near of Fillmore. Early on it was recognized the fault bifurcates into two strands near the mouth of Hopper Canyon. The Main strand is located in the foothills of the mountain front and the Piru strand trends along the northern edge of the Santa Clara River Valley. Accurate mapping of the surface fault trace along the southern mountain front east of Sespe Creek has been difficult because the fault is in close proximity to the northern margin of the Santa Clara River flood plain and any recent scarps may be obscured by erosion. The Piru strand is located some distance north of the Santa Clara River and thus recent scarps are better preserved but were not necessarily completely recognized by mappers, as evidenced by the wide variation in the mapped surface traces below. Also, the entire trace of the Piru strand is shown as buried under Quaternary alluvium by all workers and its activity was unknown, though inferred to be active. Even the portion of the Main strand up higher in the foothills, which is not active, is mapped in various locations and some workers include up to 3 distinct splays. This level of mapping accuracy was adequate until better resolution imagery was available and/or paleoseismic investigations were performed (See Sections C and D). CGS used this mapping along with recent high-resolution LiDAR data and the results of recent trenching across the Piru strand to evaluate the location and activity of the San Cayetano Fault in the Piru quadrangle (Olson, 2012).

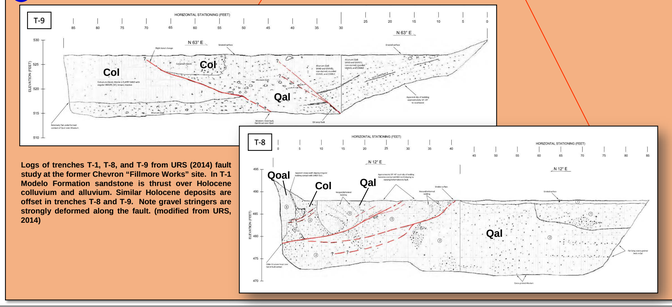


C LiDAR HILLSHADE MAP

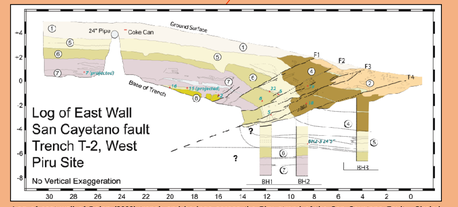


LiDAR hillshade image derived from dataset provided by County of Ventura , Public Works Agency, Watershed Protection District. Flown February 8, 2005.
Illumination direction = 315°
Illumination angle = 45°

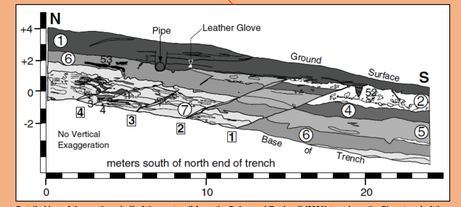
D PALEOSEISMIC INVESTIGATIONS



Logs of trenches T-1, T-8, and T-9 from URS (2014) fault study at the former Chevron "Fillmore Works" site. In T-1 Modelo Formation sandstone is thrust over Holocene colluvium and alluvium. Similar Holocene deposits are offset in trenches T-8 and T-9. Note gravel stringers are strongly deformed along the fault. (modified from URS, 2014)



Log of east wall of Dolan (2009) trench and borings across the Piru strand of the San Cayetano Fault. Circled numbers represent major stratigraphic units. F1-F4 denote the four principal fault strands. Small red triangles show locations of detrital charcoal samples. Horizontal scale is distance, along trench in meters, measured from the south end of the trench. Vertical scale is meters above or below an arbitrary datum near the ground surface at the south end of the trench. (modified from Dolan, 2009)



Detailed log of the northern half of the east wall from the Dolan and Rockwell (2001) trench on the Piru strand of the San Cayetano Fault. Numbers in square boxes denote the four principal fault strands. Small black dots show locations of detrital charcoal samples. Note strands 1 and 2 accommodated the most reverse slip during the most recent rupture event. Horizontal scale is distance, in meters, measured from the north end of the trench. Vertical scale is meters above or below an arbitrary datum near the base of the north end of the trench. (modified from Dolan and Rockwell, 2001)