Slip Rate Studies Along The Sierra Madre-Cucamonga Fault System Using Geomorphic And Cosmogenic Surface Exposure Age Constraints: Collaborative Research with Central Washington University and William Lettis & Associates, Inc.

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Abstract

In an effort to better quantify slip rates for the Sierra Madre-Cucamonga fault system, we sampled and cosmogenically dated surface samples collected from uplifted and abandoned geomorphic surfaces along the Sierra Madre-Cucamonga faults system. We studied three locations in the vicinity of the 1971 San Fernando earthquake surface rupture (Pacoima Wash, Lopez Canyon, and Wilson Canyon) and one along the Cucamonga fault (Day Canyon fan) (Figure 1). Cosmogenic ages determined for uplifted alluvial surfaces, directly north of the 1971 surface rupture indicate a dip-slip rate of 1.21 ± 0.2 mm/yr. Additional slip rates were derived for faults (0.8 ± 0.3 mm/yr and 1.2 ± 0.14 mm/yr) located north of the 1971 surface rupture to help constrain the rate of deformation across the broad, distributed fault zone. Summing these three rates suggests that the composite dip-slip rate across the broad fault zone may be as high as ~3 mm/yr, although it is questionable whether the young secondary faults cutting the Lopez fan remnant should be included due to (1) the minimum age estimate for the surface and (2) the possibility that slip on these structures may be due to flexural slip and not seismogenic slip at depth. Along the east-central portion of the Cucamonga fault zone, ^{10}Be cosmogenic surface age data indicate a mean surface age of 34,561 ± 328 yrs for the Day Canyon fan, nearly three times greater than previous estimates. Consequently, we estimate a relatively low slip rate of 1.9 ± 0.4 mm/yr across three strands of the Cucamonga fault zone at Day Canyon.

Introduction

This project was designed to provide a reliable slip rate estimate for the Sierra Madre-Cucamonga (SMC) fault system that bounds the southern margin of the San Gabriel Mountains (Figure 1). As part of this project, we (1) produced digital elevation models using the early 1920's USGS 6 minute topographic map series (5 foot contour intervals), (2) produced detailed maps of fault scarps and Quaternary geomorphic surfaces, (3) determined the age of surfaces using cosmogenic surface exposure age dating techniques (Table 1), and (4) calculated uplift rates and slip rates (Table 2) across the SMC fault system in the San Fernando and San Gabriel Valleys.

Digital elevation models (DEMs) using the early 1920's USGS 6-minute topographic map series (5 foot contour intervals) were produced. INTEC Americas Corporation produced 400 dpi 8-bit cropped geo-referenced scans of the following USGS 6-minute topographic maps, (1) 1927 Pacoima (surveyed 1924-1925), (2) 1939 Little Tujunga (surveyed 1933-1934), (3) 1942 Sunland (surveyed 1924-1925 and 1933), and (4) 1935 Sylmar (surveyed in 1925 and 1929). Our detailed maps of fault scarps and Quaternary geomorphic surfaces from the Pacoima area use these 5 m DEMs as a basemap.

CWU graduate student, Jake Horner, processed and analyzed Be and Al isotopes at the Center for Accelerator Mass Spectrometry at the Lawrence Livermore National Laboratory from samples collected from alluvial surfaces for this study. A more complete description of the sample processing and dating methods is provided in Horner (2006). The cosmogenic dating was performed with a LLNL grant under the direction of Rick Ryerson.

Pacoima Wash area

Three quartz-rich cobbles from the active Pacoima Wash (Figure 2) yield modern ^{10}Be and ^{26}Al ages, which indicate zero inheritance from the source area. Analyses using ^{10}Be and ^{26}Al surface dating methods on three cobbles from the Qt4 Pacoima Wash surface of Lindvall et al. (1995) yield surface exposure ages of 33,239 ±1564 yrs, 31,196 ±1287, and 31,024 ±1073 (Figure 2). This gives a mean surface exposure age 31,561 ± 729 years.

The minimum vertical separation across the Qt4 surface, that includes the 1971 surface rupture and two older scarps that offset Qt2-Qt5, is 27 m ± 1m. Based on 27 m of mean vertical separation across multiple fault strands along Pacoima Wash, and a mean surface age of 31,561± 729 for the Qt4 surface, we estimate a vertical uplift rate across the Sylmar fault segment of 0.8 ± 0.1 mm/yr. Field observations of the surface rupture produced by the San Fernando earthquake indicate that rupture near the ground surface occurred on a 45° dipping fault plane (Kamb et al, 1971). Assuming an average fault dip of about 45° for fault strands 1, 2, and 3, combined with an uplift rate of 0.8 ± 0.1 mm/yr, yields a dip-slip rate of 1.2 ± 0.2 mm/yr across the Sylmar fault zone, which is similar to the dip-slip rate obtained by Lindvall et al. (1995) using soil age estimates.

Lopez Canyon fan

The Lopez Canyon fan is located just west of the Lopez Canyon drainage, where alluvial deposits unconformably overlie north-dipping beds of the Plio-Pleistocene Saugus Formation (Figure 3). Despite extensive surface degradation, detailed geomorphic analysis and field mapping has delineated two southward-facing topographic lineaments that trend northwest, forming parallel scarps (S4 and S5 Figure 3). A road cut through scarp 5 exposes faulted alluvium across a fault plane dipping about 40º north. Due to extensive dissection of the Lopez Canyon fan surface, our sampling efforts were concentrated near two portions of the fan remnant that display the best-preserved surface morphology. Many cobbles exposed at these locations are heavily weathered and or fragmented, limiting our analyses to only a few suitable samples.

Analysis of the fan morphology, degree of soil development, topographic location and earlier assessments by Wills and Hitchcock (1999) and Dibblee (1991), the relative age of the fan surface is much older than the oldest abandoned terrace deposits along Pacoima Wash. However, ^{10}Be results indicate an average surface age of 29,540 ± 458 yrs, similar to ages of the terraces along Pacoima Wash. We interpret that these cosmogenic dates represent a minimum surface age due to uncertainties in sample erosion rates and burial history. Using the maximum vertical separation of 7 m across scarp 4 and 8.5 m across scarp 5 and a minimum surface age of 29,540 ± 458 years yields a maximum uplift rate of 0.5 ± 0.1 mm/yr for the entire surface. Assuming a 40˚ dipping fault plane and minimum uplift rate of 0.5 ± 0.1 mm/yr suggests a maximum dip-slip rate of 0.8 ± 0.3 mm/yr across the Lopez fan surface.

Wilson Canyon Fan

The Wilson canyon fan surface consists of a large preserved remnant that forms a southwest sloping surface along with a few smaller remnants capping ridges north of the Sylmar basin. The northern extent of the fan surface is bound by the older, north-dipping Hospital fault, which marks the southern limit of crystalline bedrock (Figure 4). The southern extent of the Wilson Canyon fan surface is bound by a topographic inflection, which represents a southward-facing scarp, informally termed the Wilson Canyon fault. This fault is not exposed in outcrop and its presence is inferred based on geomorphic break between the modern valley floor and older uplifted deposits and surfaces, as well as the presence of faults mapped along this break both east and west of Wilson Canyon. Due to extensive dissection of the original fan surface, our topographic profile (Figure 4) incorporates two bends that allow for a more accurate measurement of the true vertical separation. The total mean vertical separation across the Wilson canyon escarpment is 63 ± 5 m. This value represents a minimum vertical separation because the Wilson Canyon fan surface is buried beneath the modern alluvium on the footwall block.

Using equally weighted samples yields a mean surface age of 52,930 ± 621 yrs. Although, if the sample ages are compared to its relative degree of weathering, younger samples correlate with a higher degree of weathering, indicating that the mean surface age likely underestimates the true surface age. A better estimate of the true surface age was obtained from the three quartz-rich samples (PW-14, 16 and 18) with the lowest degree of weathering that yields a mean surface age of 65,245 ± 1049 yrs. Using a 63 ± 5 m of vertical separation and a surface age 65,245 ± 1049 yrs gives an uplift rate of 1.0 ± 0.1 mm/yr across the Wilson Canyon fault. Assuming a 61°, fault dip, with 20° uncertainty, similar to the Veterans fault (Kamb et al., 1971) located to the east, yields a slip rate of 1.2 ± 0.14 mm/yr across the Wilson Canyon fault.

Day Canyon Fan (Cucamonga fault)

The Day Canyon fan, which is offset by the Cucamonga fault, (Figure 5) provides new slip rates near Day Canyon based on 32 m of cumulative vertical separation across multiple fault scarps (Figure 6). Cosmogenic surface dating of quartz-rich alluvial cobbles from the Day Canyon Qyf1a surface (West Fan of Morton and Matti, 1987) yielded a mean surface age 34,561 ± 328 years (Figure 7a).

To the east, seven quartz-rich cobbles from the Qyf1b surface (East Fan of Morton and Matti, 1987) yielded a mean cosmogenic surface age of 25,279 ± 395 years (Figure 7b). The surface ages for the Qyf1 surfaces are substantially older than the ~13 ka estimate of Morton and Matti (1987). The difference is likely due either to the large uncertainty associated with soil age comparisons or to the lack of a well-constrained correction for inheritance among samples used for cosmogenic dating. The quartz-rich samples were collected only a short distance from the range front, suggesting a relatively short transport history that provides little time for a significant buildup of nuclide inheritance. Therefore, we interpret the mean surface age estimated using ^{10}Be cosmogenic dating is more representative of the true surface age than the soil ages. Using 32 ± 0.7 m of mean vertical separation of the Qyf1a and a surface age 34,561 ± 328 yrs gives an uplift rate of 0.9 ± 0.1 mm/yr across the Cucamonga fault Qyfla Day Canyon Fan surface. Assuming a 33° fault dip (Morton and Matti, 1987) yields a slip rate of 1.9 ± 0.4 mm/yr across the Cucamonga fault at the Day Canyon fan surface Qyf1.

Conclusions

At four selected locations, uplifted geomorphic surfaces along the Sierra Madre-Cucamonga fault system were mapped in detail and cosmogenically dated using samples collected from the surfaces of fluvial terraces and alluvial fans. Three of our study locations (Pacoima Wash, Lopez Canyon, and Wilson Canyon) are located along the western portion of the fault system in the vicinity of the 1971 San Fernando surface rupture and provide slip rate estimates across a broad, complex zone of deformation in the San Fernando Valley. The fourth location, the Day Canyon fan, is located along the Cucamonga fault near the eastern end of the fault system. Utilizing scarp heights and cosmogenic age estimates of faulted alluvial surfaces, we estimate uplift rates and dip-slip rates for faults within the Sierra Madre-Cucamonga fault system.

At Pacoima Wash we measured 27 m of mean vertical separation across multiple fault strands and estimate a mean surface age of 31,561± 729 for the Qt4 surface. Based on these data, we estimate a vertical uplift rate of 0.8 ± 0.1 mm/yr. Assuming an average fault dip of 45°, yields a dip-slip rate of 1.2 ± 0.2 mm/yr across the Sylmar fault zone.

At the Lopez Canyon fan locality we measured a maximum vertical separation of 15.5 m across two scarps that represent secondary faults within the uplifted block of Tertiary bedrock east of Pacoima Wash and north of the 1971 surface rupture. A minimum surface age of 29,540 ± 458 years yields a maximum uplift rate of 0.5 ± 0.1 mm/yr for the entire surface. Assuming a 45˚ dipping fault plane, suggests a slip rate of 0.8 ± 0.3 mm/yr for these two secondary faults. The faulting of Lopez fan surface is located on the south limb of the Merrick syncline and may or may not represent a component of seismogenic slip at depth, given that this type of deformation could be attributed to flexural-slip faulting within the fold.

At the Wilson Canyon fan remnant, a vertical separation of 63 ± 5 m and a surface age of 65,245 ± 1049 yrs suggest an uplift rate of 1.0 ± 0.1 mm/yr. Assuming a fault dip of 61° (similar to nearby Veterans fault that ruptured in 1971), yields an a dip-slip rate of 1.2 ± 0.14 mm/yr across the "Wilson Canyon fault" and the northern margin of the San Fernando Valley.

Lastly, we measured 32 ± 0.7 m of mean vertical separation of the Qyf1a surface at the Day Canyon fan locality. With a ^{10}Be surface age 34,561 ± 328 yrs, we calculated an uplift rate of 0.9 ± 0.1 mm/yr across the Cucamonga fault Qyfla Day Canyon Fan surface. Assuming a 33° fault dip yields a slip rate of 1.9 ± 0.4 mm/yr across the Cucamonga fault at the Day Canyon fan surface Qyf1. Cosmogenic dating of the Day Canyon fan surfaces have resulted in a lower slip rate for the Cucamonga fault than previously estimated using soil age estimates.

Presentations

Horner, A.H., Rubin, C.M., and Lindvall, S.C., 2007, Slip Rate Studies Along the Sierra Madre-Cucamonga Fault System Using 10Be Cosmogenic and Geomorphic Surface Age Analyses, Association of Engineering Geologists, Southern California Section, September 24-29.

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Table 1. Analytical Results of ^{10}Be Cosmogenic Dating

Sample site/number	^{10}Be[a] (10^5 atom g^{-1})	^{10}Be model age[b] (yr)	Average surface age[c] (yr)
Pacoima Wash Qt4 Surface			31,561 ± 729
PW-1	0.621 ± 0.029	33239 ± 1564	
PW-2	0.807 ± 0.033	31196 ± 1287	
PW-3	1.515 ± 0.052	31024 ± 1073	
PW-B[d]	0.554 ± 0.024	69825 ± 3055	
PW-C[d]	0.745 ± 0.025	64720 ± 2143	
Pacoima Wash			N.D.
PW-4	N.D.	N.D.	
PW-5	N.D.	N.D.	
PW-6	N.D.	N.D.	
Lopez Canyon Fan Surface			29,540 ± 458
LC-1	1.955 ± 0.060	29029 ± 884	
LC-2	2.278 ± 0.069	33443 ± 1009	
LC-3	2.194 ± 0.062	33181 ± 943	
LC-4	1.647 ± 0.058	24273 ± 851	
Wilson Canyon Fan			65,245 ± 1049
PW-13[d]	4.110 ± 0.113	52071 ± 1435	
PW-14	4.337 ± 0.108	61489 ± 1534	
PW-15[d]	3.579 ± 0.124	49265 ± 1705	
PW-16	4.980 ± 0.135	72255 ± 1955	
PW-17[d]	2.929 ± 0.076	41688 ± 1082	
PW-18	4.666 ± 0.153	64584 ± 2122	
Day Canyon Fan Surface Qyf_{1b}			25,279 ± 395
DC-1	2.044 ± 0.066	27233 ± 883	
DC-2	1.975 ± 0.068	26411 ± 906	
DC-3	2.153 ± 0.072	28578 ± 958	
DC-4	1.743 ± 0.071	23457 ± 956	
DC-5	1.744 ± 0.060	22111 ± 760	
Day Canyon Fan Surface Qyf_{1a}			33,395 ± 332
DC-6	1.975 ± 0.080	26242 ± 1069	
DC-7	2.980 ± 0.079	39739 ± 1054	
DC-8	2.999 ± 0.099	35231 ± 1162	
DC-9	2.580 ± 0.091	33182 ± 1168	
DC-10	3.292 ± 0.091	41331 ± 1142	
DC-11	3.263 ± 0.097	40911 ± 1218	
DC-A1	2.344 ± 0.099	26725 ± 1127	
DC-A2	2.972 ± 0.088	32044 ± 946	
DC-A3	2.492 ± 0.076	28761 ± 875	
DC-A4[d]	1.411 ± 0.066	15617 ± 735	

Notes: Lat/Alt-latitude and altitude correction factors; Depth/topo-depth and topography correction factor; Geomag corr-corrected for geomagnetic altitude; N. D.-no data (sample ratios were below the background ratio measured for blank samples).

[a]Propagated analytical uncertainties include error on the blank, carrier and couting statistics.

[b]Propogated uncertainties on the model ages include a 20% uncertainty on the production rate.

[c]Average surface age is a weighted mean of ^{10}Be model ages.

[d]Indicates sample that is not included in the calculation of the average surface age.

Table 2. Uplift and Dip-Slip Rates Along the Sierra Madre-Cucamonga Fault System

Geomorphic Surface	**Surface Age** (yr)	**Mean Vertical Seperation** (m)	**Mean Vertical Uplift Rate** (mm/yr)	**Assumed Fault Dip** (degrees)	**Dip-Slip Rate** (mm/yr)
Pacoima Wash Qt4	31,561 ± 729	27 ± 2	0.9 ± 0.1	45	1.2 ± 0.2
Lopez Canyon Fan	29,540 ± 458	15.5 ± 0.7	0.5 ± 0.1	40	0.8 ± 0.3
Wilson Canyon Fan	65,245 ± 1049	63.5 ± 5.0	1.0 ± 0.1	61	1.1 ± 0.4
Day Canyon Fan	34,561 ± 328	32 ± 0.7	0.9 ± 0.04	33	1.9 ± 0.35

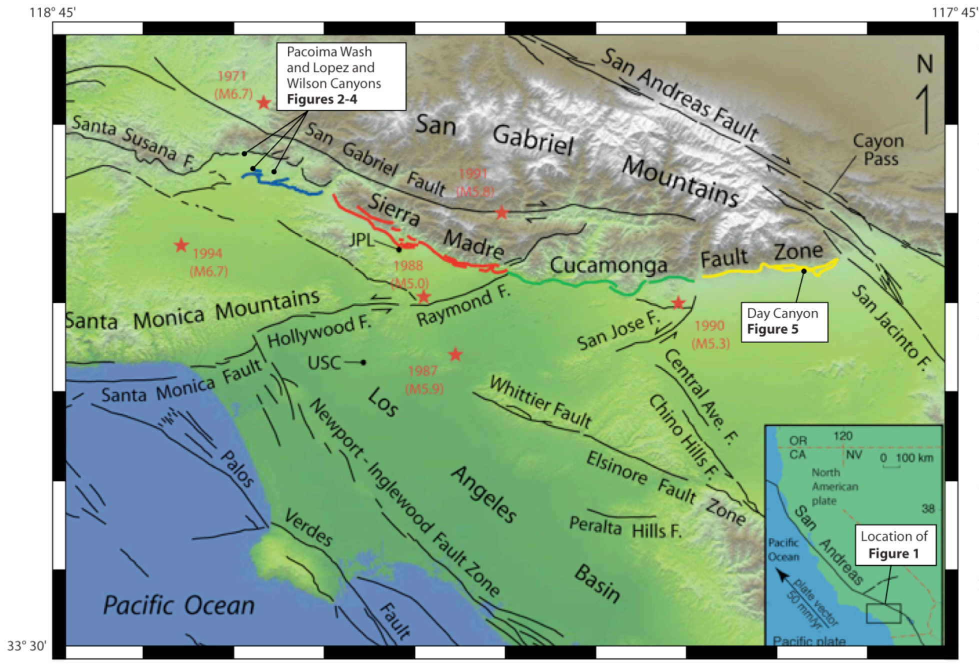

Figure 1. Fault map of southern California showing field locations, major faults, and selected earthquake epicenters since 1971. The Sierra Madre-Cucamonga fault is colored: the 1971 surface rupture along the San Fernando segment is shown in blue, the central Sierra Madre segment is show in red, the eastern segment is shown in orange, and the Cucamonga segment is shown in yellow. Fault map from Crook et al. (1987) and Jennings (1994).

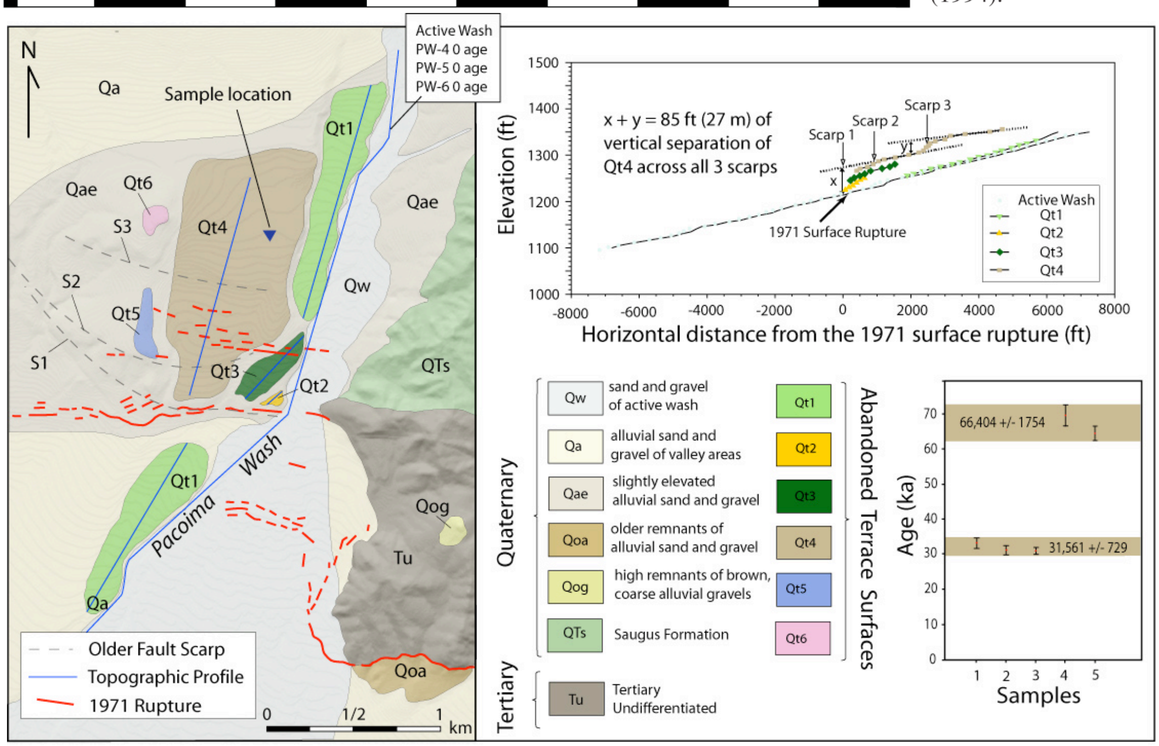

Figure 2. Abandoned alluvial terrace surfaces at Pacoima Wash along the 1971 surface rupture of the San Fernando earthquake. The 1971 rupture and additional fault scarps collectively displace Qt2 - Qt6 alluvial surfaces. Topgraphic profiles across the active Pacoima Wash and late Quaternary alluvial surfaces record about 27 m of vertical separation across the Qt4 terrace surface. Faults and geology modified from Dibblee (1991a), Kamb et al. (1971) and Barrows et al. (1975).

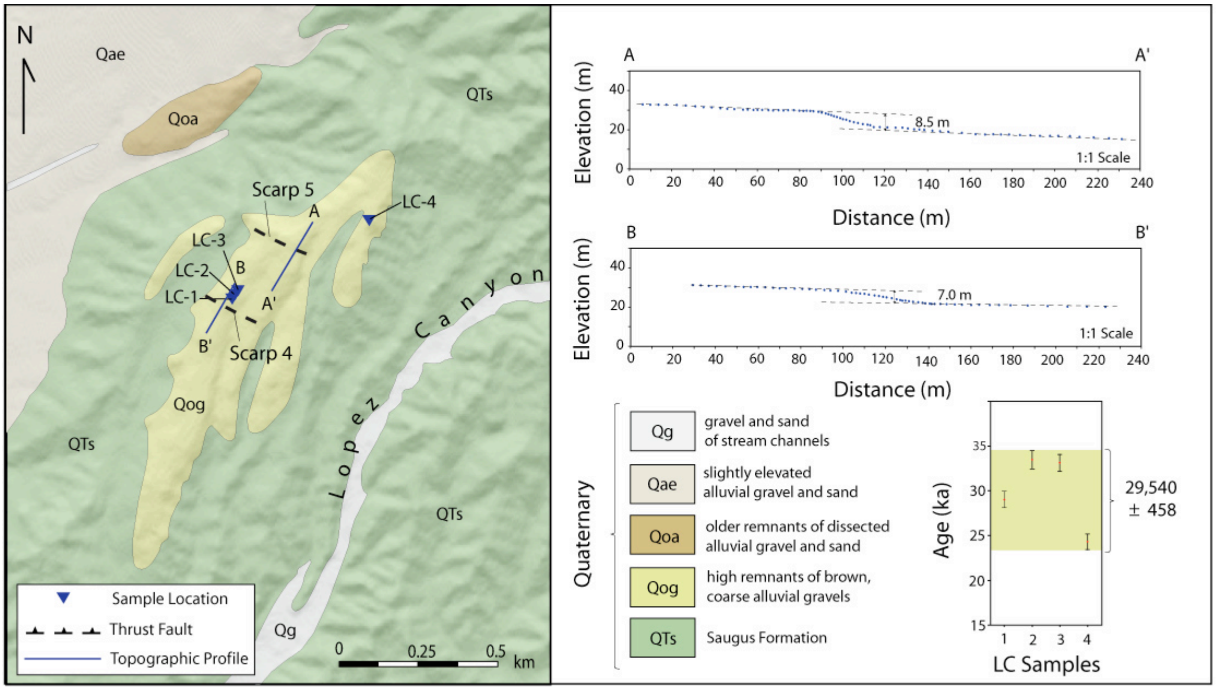

Figure 3. Geologic map of abandoned fan surface west of Lopez canyon showing topographic profile and sample locations. Topographic profiles were constructed from detailed surveys and show a cummulative surface offset across fault scarps 4 and 5 of 15.5 ± 1 meters. Surface samples yield a wieghted mean surface age of 29,540 ± 458 years. Geology modified from Dibblee (1991) and Wills and Hitchcock (1999).

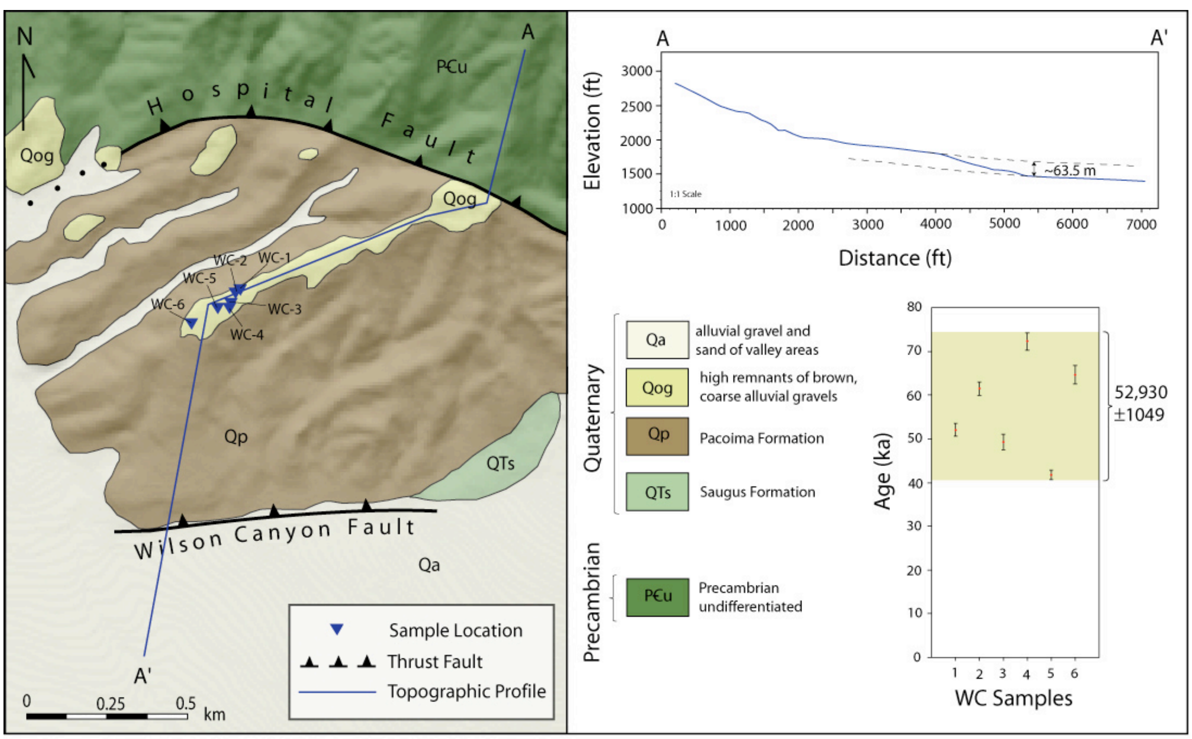

Figure 4. Geologic map of abandonded fan surface near Wilson Canyon showing topographic profile and sample locations. Topographic profiles were constructed using 5-20 ft contour maps and show a cummulative surface offset across the Wilson Canyon fault (informally named) of ~63.5 ± 5 m. Surface samples yield a wieghted mean surface age of 52,930 ± 458 years. Geology modified from Dibblee (1991) and Wills and Hitchcock (1999).

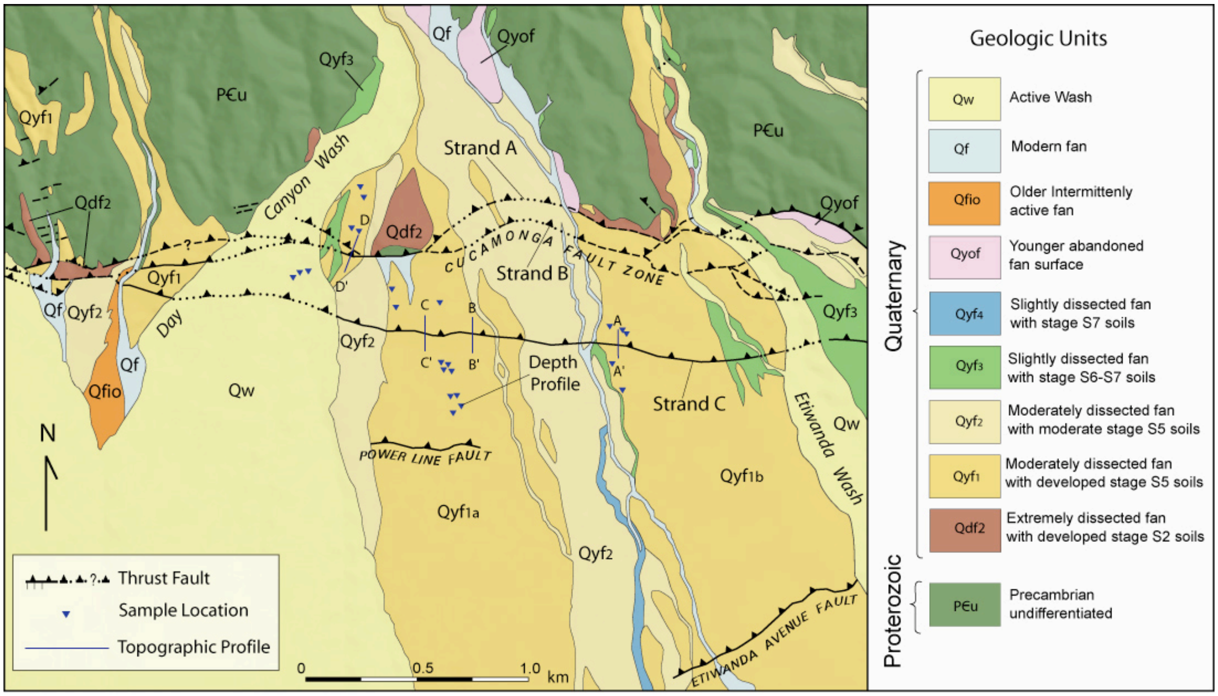

Figure 5. Geologic map of the Day Canyon Fan showing location of samples and topographic profiles. Faults and geology modified from Morton and Matti (1987).

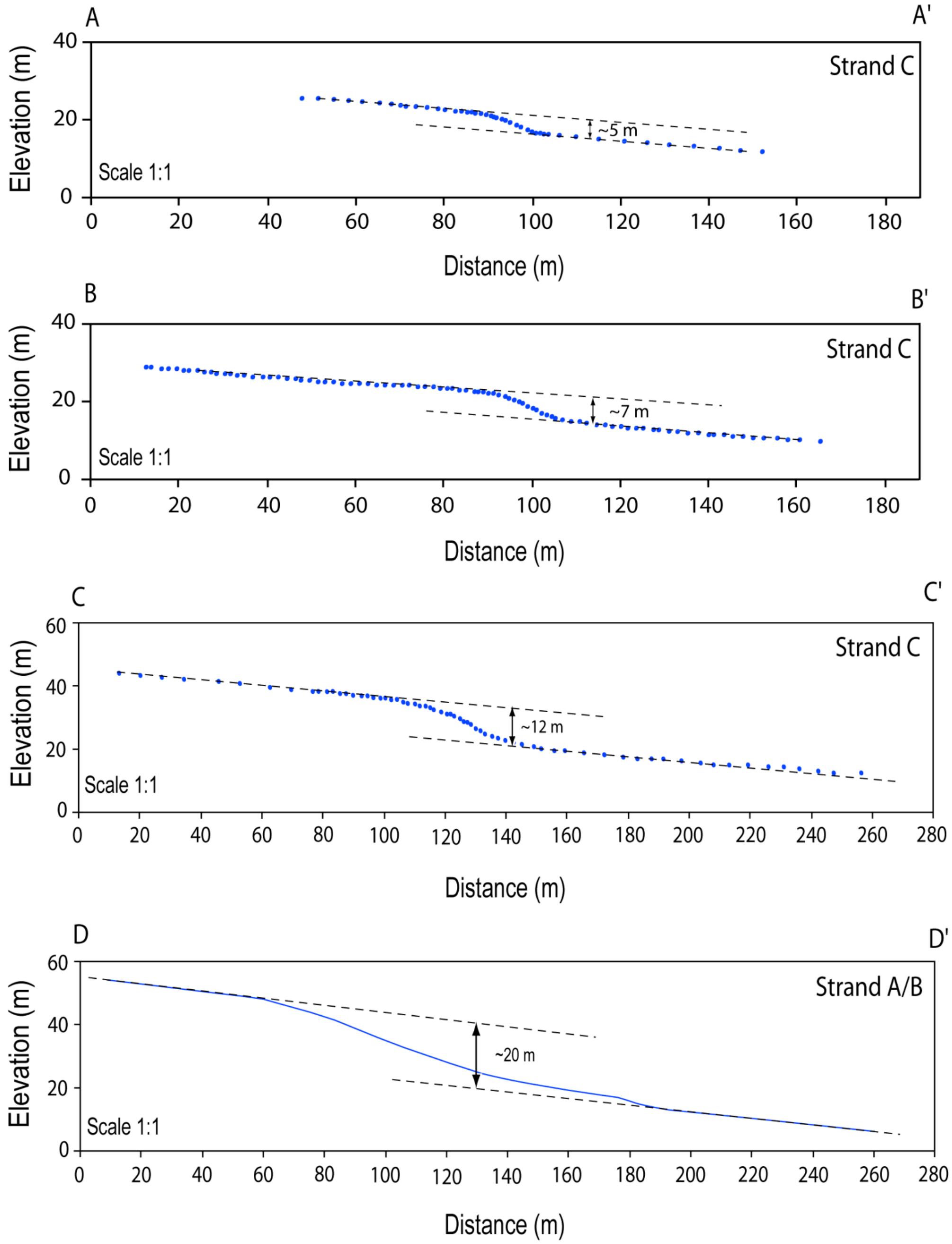

Figure 6. Topographic profiles across fault strands A/B and C along the Cucamonga fault zone near Day Canyon. Blue dots represent points surveyed using total station and blue line represents surface profile constructed using topographic maps with 4 ft contour intervals. Profiles A, B, and C illustrate the variability in scarp height along strike for strand C. Using profiles C-C' and D-D' we estimate 32 m of vertical separation of Qyf1a. Profile locations are shown with blue lines in Figure 5.

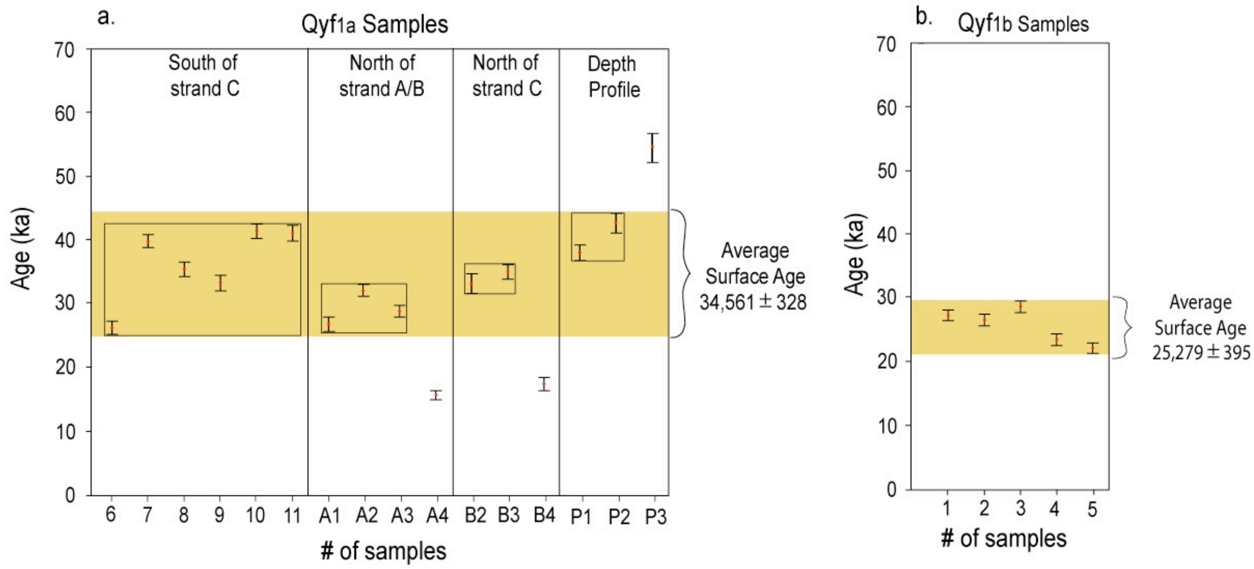

Figure 7. a. Model ages calculated for samples from unit Qyf1a on the west Day Canyon Fan. Average surface age is a weighted mean of 10Be model ages, excluding samples that plot outside the colored box. b. Model ages calculated for samples collected from unit Qyf1b on the east Day Canyon Fan. Error bars represent propogated uncertainties including 20% uncertainty on the production rate. Average surface age is a weighted mean of 10Be model ages, excluding samples that plot outside the colored box.