2025 SCEC Annual Report

Project Description

In this study, cosmogenic radionuclides were calculated to quantify denudation rates along the restraining bend of the Calaveras and Hayward faults in the Diablo Mountain Range and Mission Hills. $^{10}$Be cosmogenic denudation rates measured along the range front of the Diablo Mountain Range, near the the Arroyo Aguague Reverse and Mission Hills Fault appear to increase northwestward, as slip from the Calaveras Fault is transferred to the Hayward Fault.

$^{10}$ Be-derived catchment-wide erosion rates for 15 watersheds between the Calaveras and Hayward Faults range from 0.047 mm/y to 0.161 mm/yr, appear to support a landscape that is in topographic equilibrium. We find that low erosion rates from the southern Diablo Mountains, where the Calaveras Fault steps left to the Hayward Fault, are consistent with similarly low mean slope, low local relief (100m and 1500m) and low $k_{sn}$ values. This pattern suggests that crustal uplift and overall topography may control erosion rates here. Second, we find that $^{10}$ Be-derived erosion rates from the southern Diablo Mountains may reflect variations from increased tectonic uplift from south to north. In landscapes that are in topographic equilibrium, it is expected that hillslopes and channels are coupled, and the topographic metrics representing channel steepness and hillslope gradient show similar patterns with erosion rates. These data suggest that fault geometry and active faulting may have a strong influence on the landscape. The region is a restraining bend that is accommodating transpression between the Calaveras and Hayward Faults.

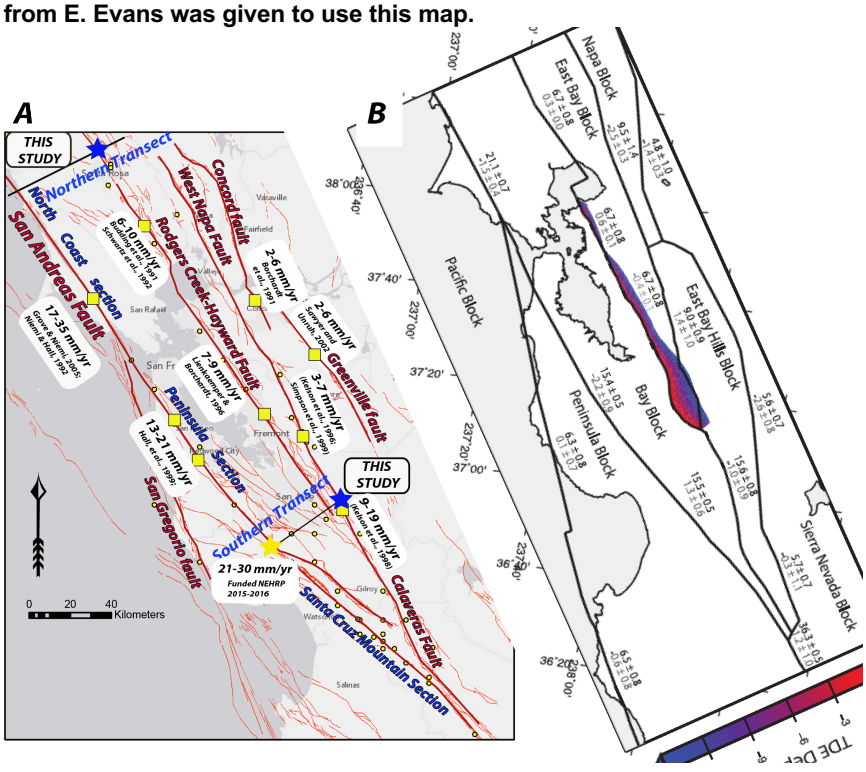
These results align with SCEC science priorities, specifically:

- assessing and improving the quality of the SCFM (A1-1, A3-1);
- reconciling inconsistencies between the SCFM and the National Seismic Hazard Model (NSHM) faults [Hatem et al., 2022] (A3-1);
- identifying locations across the SAF System in the southern Bay Area where new paleoseismic observations will best constrain surface rupture behavior (A1-3);
- constraining slip rates in populated areas (A3-4).

The transform plate boundary between the Pacific and North America plates is made up of a system of strike-slip faults that cut urban northern California into crustal blocks. The movement of these blocks past one another produces earthquakes, one of the greatest natural hazards affecting northern California. Geodetic block model studies estimate the San Andreas Fault

(SAF) accumulates interseismic strain equivalent to motions of up to ~17-21 mm/yr of the ~50 mm/yr motion across the plate boundary [e.g., *d'Alessio, et al., 2005; Evans et al., 2012*] (Fig. 1). The remaining strain is distributed eastward and westward on multiple faults, the (1) Concord—Green Valley—Calaveras, (2) Rodger's Creek—Hayward, and (3) San Gregorio [e.g., *d'Alessio, et. al., 2005; Evans et al., 2012*]. The Hayward and Calaveras faults are part of the dextral SAF system that strikes across several urban areas. Here, active faulting and slip partitioning between these faults is manifested in the Diablo Mountain Range and Mission Hills, where the right lateral Hayward Fault steps left to the Calaveras Fault. These faults currently accommodate ~20-44% of the relative PA-NA plate motion in northern California and have generated 13 $M_L$ > 5 earthquakes since 1850 [*Oppenheimer et al., 1990*]. Where plate boundary deformation is partitioned onto the Hayward Fault, detailed geomorphic and paleoseismic studies on the northern Calaveras Fault show slip rates of 3-7 mm/yr [*Kelson et al., 1996; Simpson et al., 1999*] (Figure 1). These Holocene geologic slip rates combined with rates from the Hayward Fault of 7-9 mm/yr to the west [*Lienkaemper and Borchardt, 1996*] and rates from *Kelson et al.*, [*1998*] for the central Calaveras Fault suggest a broad range of slip rates for the central Calaveras Fault of ~9-19 mm/yr.

**Figure 1. Maps showing active faults of northern California. (A) Geologic slip rate summary map. The trace of the main San Andreas Fault (SAF) is partitioned into three sections: (1) North Coast, (2) Peninsula, and (3) Santa Cruz Mountains. The yellow squares show the location of published slip rate sites. The white boxes next to each square shows the geologic slip rate determined along with the reference for each slip rate site. The yellow star shows the location of a new slip rate site on the Santa Cruz Mountain section of the SAF funded by NEHRP in 2015-2016 to Blisniuk, SJSU. The blue stars show the location of new sites on the Calaveras fault (along a southern transect) and on the Rodgers Creek fault (along a northern transect) by PI Blisniuk. The yellow dots show the location of paleo-earthquake sites summarized in *Toppozada, et. al., 2002*. (B) Block model slip rate map from Evans et al., (2012) across faults that make up the northern SAF. Permission from E. Evans was given to use this map.**



In this study, cosmogenic radionuclides were used to quantify denudation rates along the restraining bend of the Calaveras and Hayward faults in the Diablo Mountain Range and Mission Hills. Uplift between the Calaveras and Hayward faults is estimated using denudation rates from river sands (via $^{10}$Be concentrations) and these rates of 0.047 mm/y to 0.161 mm/yr, provide information on how slip maybe partitioning between the Calaveras and Hayward faults. Together, denudation rates and topographic metrics give us a comprehensive understanding of how surface processes and tectonic forces shape a landscape [e.g., *Whipple & Tucker, 1999; Binnie et al., 2007DiBiase et al., 2010; Hurst et al., 2013; Argueta et al., 2023*] (Figure 2.). Studies of the Hayward and Calaveras faults have quantified slip rates for different sections of the faults [*Lienkamper & Borchardt, 1996; Kelson et al., 1998; Simpson et al., 1999*], and microseismicity studies show these faults are connected at depth [*Chaussard et al., 2015*].

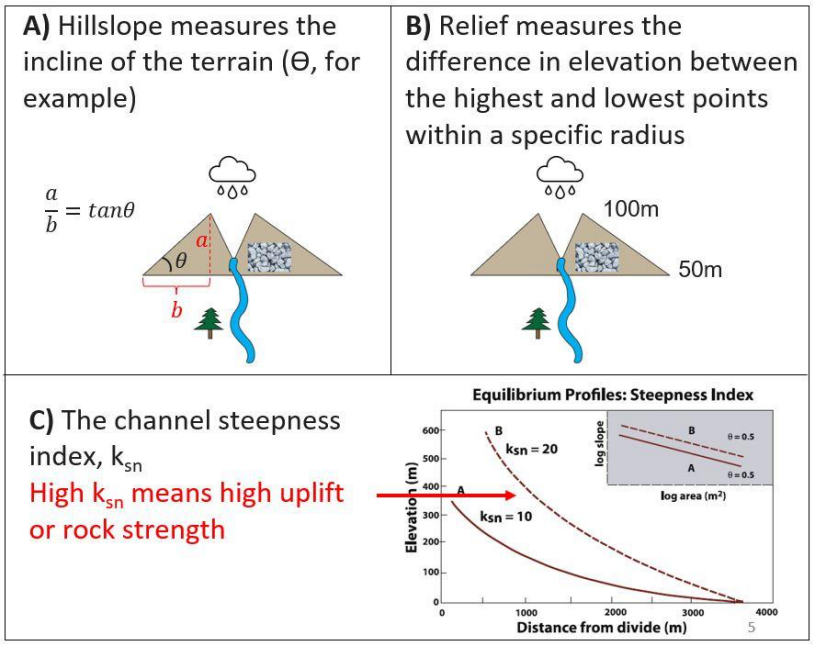



**Figure 2. Summary describing topographic metrics used in this study to assess whether erosion rates are in equilibrium with the uplift rate. (A) Hillslope angle, measuring the incline of the terrain, serve as sensitive indicators of tectonic uplift. (B) Local relief (the elevation difference between the highest and lowest points), within a specific radius, aids in identifying geological features influenced by tectonics, denudation, or climatic conditions. (C) Channel steepness index (ksn) allows comparison to uplift and rock strength across a basin. Under constant rock strength and uplift, ksn should remain consistent throughout a basin. High ksn means high uplift or rock strength, as indicated by the graph on the right (Kirby and Whipple, 2012).**

$^{10}$Be cosmogenic denudation rates were measured along the range front of the Diablo Mountain Range along strike to document trends in uplift rate (for the Arroyo Aguague Reverse Fault) and exhumation of the Diablo Mountain Range (Figure 3). These denudation rates were compared to topographic metrics between these faults using Digital Elevation Models and MATLAB's Topo Tool Box [*Argueta et al., 2023, Scherler & Schwanghart, 2014*]. Previous studies in southern California have applied this method in the San Bernardino [*Argueta et al., 2023, Binnie et al., 2007*] and San Gabriel Mountains [*DiBiase et al., 2010*] to show how tectonics may or may not be reflected in the landscape.

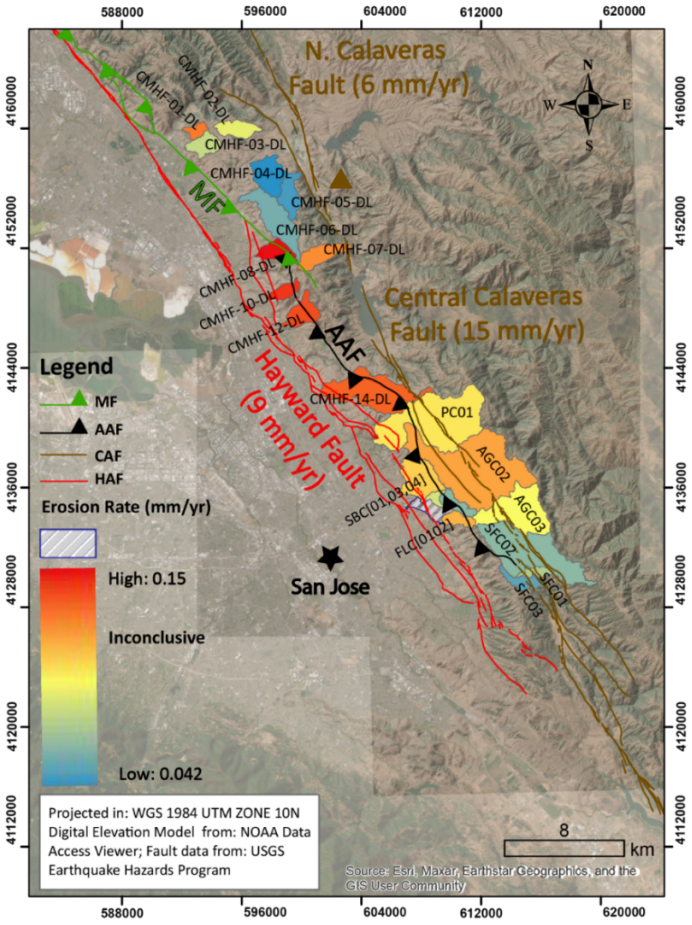



**Figure 3. Results of denudation rates along the Hayward Fault: Erosion rates are displayed on a hillshade map covering the entire restraining step, from the junction of the Hayward and Calaveras faults in the southeast, extending to the Calaveras Fault terminus in the north. Fault lines are delineated (USGS, 2004): Arroyo Aguague Fault (AAF) in black, the Mission Fault (MF) in green, the Hayward Fault Zone (HAF) in red, and the Calaveras Fault Zone (CAF) in brown. The erosion rates, represented by the cool to warm colors, generally increase from the southeast to the northwest and then decrease again in the northernmost basins. Denudation rates from east to west and north to south are compared to visualize how slip is partitioned from the Calaveras Fault to the Hayward Fault in the southern restraining step. The slip rates are 15 mm/yr for the Central Calaveras Fault, 6 mm/yr for the Northern Calaveras Fault, and 9 mm/yr for the Hayward Fault.**

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