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Refining Late Quaternary History on the Santa Cruz Island Fault

A Thesis submitted in partial satisfaction of the
requirements for the degree Master of Science
in Earth Science

by

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June 2026

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ABSTRACT

Refining Late Quaternary History on the Santa Cruz Island Fault

by

Joshua Sanders Love

The utilization of tectonically offset geomorphic markers to quantify differential motion between adjacent crustal blocks provides constraints on the kinematics of active fault systems and their associated hazards. These geological data are foundational inputs for probabilistic seismic hazard analyses (PSHAs), which inform regional building codes that are designed to reduce loss of life during earthquake events.

The Santa Cruz Island Fault (SCIF) is an ~83 km-long segment of the larger ~200 km-long Western Transverse Range (WTR) fault system in Southern California. The SCIF's proximity and structural connection to the Los Angeles basin have implications for earthquake hazard models that impact ~20 million people. Current PSHA's for the entire fault rely on geologic data based on the westernmost ~3 km segment. This study analyzes ~13 km of the terrestrial segment of the SCIF using field mapping, 1-m resolution LiDAR, radiocarbon and luminescence dating. I measured 75 lateral and 6 vertical geomorphic offsets, distinguished up to 4 alluvial fan generations ranging in age from ~100–0.5 ka, identified three discrete earthquake events recorded in the offset channels, and estimate a maximum lateral displacement of ~3 m per event using a cumulative offset probability

density function. My preliminary post-infrared infrared stimulated luminescence (post-IR IRSL) age for an offset alluvial deposit yields a minimum recurrence interval of 7.5 ± 1.5 ky, and minimum open interval lateral slip rate estimate of 0.5 ± 0.2 m/ka for the Cañada del Medio segment. Additionally, this study's preliminary IRSL ages for Christi valley alluvial deposits and the T2 marine terrace indicate these deposits are younger than previously assumed, suggesting that the age correlations used in the previous slip rate estimate for this segment should be revised.

TABLE OF CONTENTS

1. Introduction	1
1.1. Geographic location and relationship to surrounding faults	2
1.2. Geology of the terrestrial Santa Cruz Island Fault	3
1.3. Previous work focused on Quaternary slip along the Santa Cruz Island Fault	4
2. Methods	5
2.1. Geologic mapping	6
2.2. Subdivisions of Quaternary units	7
2.3. Geochronology of Quaternary units	8
2.4. Radiocarbon geochronology	8
2.5. Infrared-stimulated luminescence (IRSL) dating	9
2.6. Measuring fault offsets	10
2.7. Cumulative offset probability density	11
3. Results	11
3.1. Cañada del Medio segment	12
3.2. Christi segment	13
3.3. Offset along the Santa Cruz Island Fault	14
3.4. IRSL age and uplift rates for T2 near Forney Cove	15
4. Discussion	16
4.1. Relative and absolute ages: Cañada del Medio	16
4.2. Relative and absolute ages: Christi	18

4.3. Controls on unit and offset preservation along the fault.....	19
4.4. Age and uplift for T2 at Forney Cove	19
4.5. Cumulative offset probability density	20
4.6. Quaternary slip at Cañada del Medio	21
4.7. Re-evaluating the slip rate at Christi Beach.....	22
5. Conclusions	22
Appendix.....	24
Tables	24
Figures	29
Bibliography	43

1. Introduction

For over half of a century, geologists have utilized tectonically offset geomorphic markers to quantify differential motion between adjacent crustal blocks to better understand active fault systems and their associated hazards (e.g., Wallace, 1968; 1990; Sieh, 1978; Sieh & Jahns, 1984). This traditional method, along with other various paleoseismological techniques, has revealed individual fault kinematics (e.g., Harrichhausen et al., 2022; Morell et al., 2017) recurrence intervals (e.g., Akçiz et al., 2010; Dolan et al., 1997; Horst et al., 2020), fault slip variability (e.g., Duckworth et al., 2021; McKenzie et al., 2022; Rodriguez Padilla & Oskin, 2023), and slip-per-event estimates (e.g., Akçiz et al., 2023).

Early paleoseismology studies relied on radiocarbon dating of relatively large charcoal samples (e.g., Sieh, 1978; Sieh & Jahns, 1984). For example, along the Santa Cruz Island Fault, detailed field measurements of offset geomorphic features were made in the 1970's (Patterson, 1979, unpub. M.S. thesis), but the study notes a lack of dateable radiocarbon material to constrain the timing of displacement. The adoption of accelerator mass spectrometry (AMS) in the 1990s enabled dating of much smaller charcoal fragments, improving the temporal resolution of earthquake events (e.g., Weldon et al., 2002; Fumal et al., 1997), and was applied to the westernmost segment of the SCIF to constrain a recurrence interval (Pinter et al., 1998a).

Recent advances in high-resolution topographic data and geochronologic techniques now allow for more detailed estimates of fault displacement and timing than previously possible.

Light detection and ranging (LiDAR) provide sub-meter resolution datasets that improve identification and measurement of geomorphic offsets, especially for difficult-to-access or heavily vegetated areas (e.g., Madin et al. 2021; Morell et al. 2017). Luminescence dating constrains the time since deposition and extends far beyond the age limits of radiocarbon dating (Mahan et al., 2023). For example, post-infrared infrared stimulated luminescence (from here on referred to simply as IRSL) methods can yield age estimates up to 500 ka (Buylaert et al., 2012). Together, these approaches offer the ability to reduce uncertainties associated with both displacement and age estimates, providing new spatial and temporal constraints on Quaternary deformation along the Santa Cruz Island Fault.

In this study, I analyze ~13 km of the terrestrial segment of the SCIF (Fig. 1). I integrate measurements of fault offset from 1-m resolution LiDAR (USGS, 2010) with detailed Quaternary geologic field mapping, along with radiocarbon and luminescence dating (locations in Fig. 2), to quantify the frequency, timing, kinematics, and magnitude of Quaternary slip, and to evaluate how strain is accommodated along-strike of the SCIF system.

1.1. Geographic location and relationship to surrounding faults

The tectonics of southern California, including the Santa Cruz Island Fault (SCIF), are dominated by the San Andreas Fault, which defines the transform boundary between the Pacific and North American plates (Atwater, 1970; Dickinson & Snyder, 1979). The San Andreas Fault is a right-lateral strike-slip fault with a major bend just north of Los Angeles (Crowell, 1979; Yerkes et al. 1965). A conjunction at the “Big Bend” occurs between the San Andreas Fault, the Garlock Fault, and the Western Transverse Range fault system

(Atwater & Stock, 1998). Both the Garlock Fault and Western Transverse Range fault systems accommodate predominantly left-lateral motion with a relatively smaller reverse component (Hornafius et al. 1986; Dolan et al., 1997; Nicholson et al. 1994). The steep, uplifting regions of northern Los Angeles and adjacent offshore faults are an expression of this converging fault network (Seeber & Sorlien, 2000). Santa Cruz Island, along with the other four Northern Channel Islands, represent the westernmost expression of the ~200 km long Western Transverse Range fault system (Sorlien, 1994).

Constraining three-dimensional displacement along offshore faults is often more challenging than onshore faults because interpretations rely primarily on indirect geophysical data, despite significant advances in marine geophysical surveying that have improved offshore fault mapping (Gulick et al. 2013; Worthington et al. 2010). The five Northern Channel Islands offer a series of terrestrial windows with which to estimate localized uplift, displacement, and timing of earthquake events on this largely offshore segment of the Western Transverse Range fault system. Constraining Quaternary deformation on the Northern Channel Islands provides opportunities to collect datasets relevant to probabilistic seismic hazard analyses (PSHAs) for Southern California, which is one of the most populated regions of the country, where fault geometry and slip rate are primary inputs (e.g., Hatem et al. 2022; Fields et al. 2014).

1.2. Geology of the terrestrial Santa Cruz Island Fault

Santa Cruz Island's central valley is a fault-bounded depression where Miocene-aged Santa Cruz Island Volcanics make up the northern fault block, and the southern block is composed of exhumed pre-Jurassic schist, Jurassic intrusives of variable mafic to felsic

composition, and Miocene volcanoclastic sediments. The entire fault generally strikes $\sim 285^\circ$, and dips $\sim 80^\circ$ north at the westernmost exposure, where slip concentrates along one main fault plane. At the eastern end of the island the fault divides into multiple strands that define the margins of the valley, however, I see no evidence of recent surface ruptures on the southern strand in this area. Large stream channels incise near-perpendicularly across the fault for most of the length of the terrestrial segment, many of which display meter-to-hundreds of meter scale offsets and rare exposures of fault contacts between the Miocene volcanics to the north, and various geologic units to the south. Quaternary alluvium and fluvial sediments fill much of the mountain fronts and valley floor along the fault.

1.3. Previous work focused on Quaternary slip along the Santa Cruz Island Fault

The time of the most recent surface-rupturing earthquake and recurrence interval estimates are critical geologic inputs for PSHAs (Morell et al., 2020). At the westernmost terrestrial exposure of the SCIF, six radiocarbon samples from a paleoseismic trench (Fig. 3C; Pinter et al. trench) were used to infer a recurrence interval of approximately 4–5 ka, and to bracket the most recent earthquake event to ~ 5 ka (Pinter et al., 1998a).

Three emergent marine terraces north of the fault, and two marine terraces south of the fault, were used as age constraints for estimating lateral and vertical slip rate for the Santa Cruz Island Fault (Pinter et al. 1998a). The lowest terrace on both sides of the fault (T1; ~ 7 –16 m above sea level) has been assigned to Marine Isotope Stage (MIS) 5e (~ 120 ka) based on U-series ages from fossils found in these deposits (Pinter et al. 1998a; 2003; Muhs et al.

2021). The second-lowest terrace (T2; ~20–40 m above sea level) currently has no age constraints, but has been speculated to have formed during either MIS 7 (~230 ka) or MIS 9 (315 ka) sea level highstands (Pinter et al. 1998a; 2003; Muhs et al. 2021). Finally, the highest terrace (T3; 100–120 m above sea level) has a minimum age estimate of ~315 ka (MIS 9) based on relative terrace elevations with respect to T1, with a preferred age of ~400 ka (MIS 11), and a maximum age estimate of ~2 Ma, based on Sr-isotope data from fossils on the highest terrace at Potato Harbor, on the northeast side of Santa Cruz Island (Muhs et al. 2021).

Previous work correlated the elevations of offset fluvial channels (Fig. 2) with the T3 marine terrace on the western side of Santa Cruz Island to estimate an open interval lateral slip rate, which is a slip rate that does not have a bounding age for the most recent event. To do this, the authors estimated ages for the lowest and highest marine terraces (T1 and T3, respectively), and an average offset measurement of 322 ± 22 m based on six offset channels. Pinter et al. (1998a) provided a minimum lateral and vertical slip rate of 0.8 m/ka and 0.1–0.2 m/ka, respectively, for the Santa Cruz Island Fault since 120 ka.

2. Methods

This study provides new constraints on lateral displacement, magnitude, slip-per-event, and number of surface-rupturing Quaternary events on the SCIF using a combination of methods. First, I conducted detailed field and LiDAR mapping within a ~1 km swath of the fault on the northern side of the valley, focused on the Santa Cruz Island Fault’s relationship to the surrounding bedrock and Quaternary geology. Second, we estimate the amount of

lateral and vertical fault displacement recorded in along-strike for a total of ~13 km of the terrestrial segment of the SCIF using both field observations and LiDAR-derived measurements of channel geometries, terrace risers, and fault scarp profiles. Third, I estimate time of downstream (downthrown side of fault) channel formation by targeting Quaternary units to collect charcoal for radiocarbon dating, as well as sand-rich layers within the downstream alluvial fan deposits for infrared stimulated luminescence (IRSL) of feldspar. Combined, these methods provide new estimates for the kinematics, timing, and displacement of Quaternary paleoseismic events along the SCIF. Each of these methods are heavily reliant on lidar-derived 1-m resolution bare-earth digital elevation models (DEMs) (USGS, 2010), which allows for DEM-derivative products (e.g., hillshade, slope, surface roughness, etc.), and precise measurements of fault-related geomorphic features at the meter-to-sub meter scale, including scarp morphology, channel offsets, and alluvial fan surfaces.

2.1. Geologic mapping

In this study, I focus on how offset bedrock and Quaternary units reveal short- and long-term timing and style of deformation along the length of the fault. Because of this, I primarily distinguished between bedrock, Quaternary alluvial/fluvial deposits, and Quaternary marine terrace units. The mapped study areas are shown in Fig. 3 and their respective locations are shown in Fig. 1. For this study, I combined pre-Jurassic schist, Jurassic intrusives (Willows Fm.), and Miocene volcanoclastics (Blanca Fm.) as one bedrock unit because I did not find any locations where distinguishing these units was helpful for observing Quaternary-related fault offsets.

Previous Quaternary geologic mapping by Schmidt et al. (2019) provided a strong foundation for locating Quaternary units that surround the fault, as well as determining relative ages. I did not map some of the relatively thin surficial geomorphic units that Schmidt et al. (2019) maps, such as hillslope deposits.

I used a series of field observations and LiDAR analysis to distinguish relative ages among alluvial units and their aerial distribution and thickness (Table 1). My methods relied on sedimentologic descriptions, soil development, topographic position relative to active channels, fan surface roughness, and cross-cutting relationships with younger alluvial deposits (e.g., Frankel & Dolan, 2007).

Relative ages were initially assigned using LiDAR, on the basis that: 1) older alluvial surfaces are generally found at higher-elevation relative to younger surfaces and/or modern active channels. 2) Older alluvial fan remnants tend to have relatively higher surface roughness due to prolonged sediment starvation and dissection. 3) Younger fan deposits are commonly inset into older alluvium. After distinguishing these units, I used field observations of sedimentology, clast characteristics, and soil development (e.g., Regalla et al., 2021) to refine the mapping.

2.2. Subdivisions of Quaternary units

Weathering rates and characteristics of Quaternary alluvium may differ across the island, therefore, I subdivide my Quaternary alluvium (Qal) mapping into three different region-specific labels: northeast (NE Qal), southeast (SE Qal), and Christi (Ch Qal). Where NE Qal and Ch Qal derive from SCI Volcanic parent rock, and SE Qal derives from schist parent rock.

2.3. Geochronology of Quaternary units

To constrain depositional ages of Quaternary alluvial, fluvial, and marine terrace deposits, I collected seventeen charcoal samples for radiocarbon (^{14}C) dating (Fig. 2; yellow dots) and eight sediment samples for post infrared infrared-stimulated luminescence (post-IR IRSL; referred to as “IRSL” from throughout the remainder of the text) dating (Fig. 2; pink dots). Sample localities were selected based on: (1) their potential to constrain relative ages of mapped alluvial units; (2) accessibility, and; (3) the presence of datable material (charcoal and/or sandy layers). Where possible, I compare ^{14}C ages with IRSL ages from the same deposits to increase confidence in age estimates.

Three of these IRSL samples came from Quaternary marine terraces to provide absolute age constraints where previous slip rate estimates relied on relative dating methods. Previous work estimated the ages of offset fluvial terraces by correlating their elevations with the T2 and T3 marine terraces (Pinter et al. 1998a). I directly dated the T1 and T2 terraces using IRSL to revisit these age assumptions and compare uplift rates.

2.4. Radiocarbon geochronology

When available, I used charcoal to estimate the ages of alluvial fans (Table 2) because it can be collected from coarse deposits whereas the luminescence dating method is best applied on sediments with finer grain sizes. In most cases, I interpret charcoal as the maximum depositional age for deposits because, typically, charcoal is older than the deposit in which it is found (Muhs et al. 1992). However, bioturbation and mixing can cause younger samples to contaminate older samples and deposits (Muhs et al. 1992; Muhs et al.

2026; Madsen et al. 2011), and charcoal samples approaching the upper limit of ^{14}C dating become less reliable (Reimer et al. 2020). While it is common practice to choose the youngest ages as the age of a deposit and assume older ages have mixed in, some samples, such as SCR2503 and SCR2504, produced modern or anomalously young ages. I report results from all samples in Table 2, but geomorphic context is taken into account and the anomalously young ages were not used for analyses.

2.5. Infrared-stimulated luminescence (IRSL) dating

In addition to radiocarbon dating, post IR-IRSL dating was used to estimate the timing of deposition for Quaternary units of interest (Table 3). IRSL aims to constrain the amount of time since mineral grains were last exposed to sunlight and subsequently buried (Huntley, 1985; Aitken, 1998; Rittenour, 2018). In alluvial fan deposits, partial bleaching is common and may cause overestimation of the time since deposition (Rittenour, 2008), therefore, my sampling efforts focused on fine-to-medium sand layers where grains are most likely to have experienced adequate sunlight to “reset” prior to burial (Nelson et al. 2015; Madsen et al. 2009). IRSL was selected instead of optically stimulated luminescence (OSL) in quartz because the deposits I targeted derived predominantly from volcanic parent material with insufficient abundance of quartz for reliable OSL measurements (Lawson et al. 2012; Rhodes, 2011; Smedley & Skirrow, 2020).

At the time of writing, final IRSL results for the eight samples were not available, therefore I use preliminary results from four of my IRSL samples as age constraints for deposits (Table 3; highlighted orange).

2.6. Measuring fault offsets

I use the Matlab user interface *LaDiCaoz* (Zielke & Arrowsmith, 2012) to measure vertically and horizontally offset geomorphic channels and deposits (e.g., Haddon et al. 2016; cite others here) visible on a 1-m resolution lidar DEM (USGS, 2010). For horizontal measurements, this method assumes that geomorphic features were initially straight prior to displacement events (McGill & Sieh, 1991; Sieh & Jahns, 1984; Zielke et al. 2010; 2012; Zou et al. 2026). For vertical displacement, this method assumes that these features had a constant gradient prior to any earthquake events since the time of deposition (Arrowsmith & Zielke, 2009).

I measured lateral offsets using features including channel thalwegs, channel levees, and interfluves. Vertical offsets were measured using offset alluvial surfaces only. I opted to avoid using active channel thalwegs for vertical offsets within the channels for two reasons: 1) active erosion since the time of earthquake events may cause my measurements to underestimate displacement, and 2) retaining walls that are up to ~2 m tall were installed in many channels along the fault by ranchers, especially in Cañada del Medio. These walls alter scarp morphology at some sites.

Various methods have been used for measuring fault offsets remotely and estimating uncertainty in the literature (e.g., Stewart et al. 2018; Haddon et al. 2016; Regalla et al. 2021; Zielke et al. 2012; Morell et al. 2017). Here, I measured each offset feature three times on different days to reduce bias. Using the *LaDiCaoz* user interface, I visually estimate the maximum, minimum, and optimal fit offset, then report the mean optimal fit ± 1 standard error for the three measurements.

2.7. Cumulative offset probability density

I calculated a cumulative offset probability density (COPD) using all lateral offset measurements that are 20 m or less (e.g., McGill and Sieh, 1991; Zielke et al. 2012). Each offset measurement is represented as a probability density function using the mean optimal fit and asymmetric uncertainties based on the standard error of the maximum and minimum offset measurements. Peaks in the COPD correspond to offset values that are most commonly found along the fault. These peaks are often interpreted to reflect discrete surface-rupturing earthquake events, where the tallest peak is likely to represent the most recent event (e.g., Salisbury et al., 2012; Zielke et al., 2012). My <20 m lateral offset dataset is limited to 35 measurements, therefore, decimal-precision peak values are sensitive to each measurement input. Due to the lack of robustness in our dataset, I do not attempt to compute uncertainty for each mode and instead use the COPD to identify generalized modal peaks at the meter-scale.

3. Results

These results provide new constraints on the ages of Quaternary alluvial and fluvial deposits, fault displacements, displacement per event, and slip rate along the Santa Cruz Island Fault. Below, I first describe the mapping and geochronological constraints for Quaternary units in the two main study areas (Fig. 3A & 3B = Cañada del Medio; Fig. 3C = Christi), where I identify sequences of 3–4 alluvial fans and inset fluvial units that range in age from ~100–0.5 ka (Table 1 has detailed descriptions of alluvial fan deposits). Then, I present fault offset measurements along the main fault strand, which range from meters to

hundreds of meters. Using a cumulative offset probability density (COPD) plot, we estimate three surface rupturing earthquake events. Finally, I present new preliminary age results for the second marine terrace (T2), which was previously used to estimate ages for offset deposits in the Christi valley but had not been dated directly.

3.1. Cañada del Medio segment

My mapping suggests that the north side of the valley contains four generations of alluvial fans (NE Qal 1–Qal 4), while the south side has three (SE Qal 1–3) (Fig. 3A & 3B; cross sections shown in Fig. 4 & 5). On the north side of the valley, I observe thin remnant alluvial surfaces ~30–60 m above the modern channel (NE Qal 1), thicker surfaces incised into NE Qal 1 that display high cementation and weathering at ~10–30 m above the modern channel (NE Qal 2), others that directly interact with the modern channel that display little-to-no dissection (outcrop examples in Fig. 7).

The alluvial deposits on each side of the valley have distinct characteristics that are dependent on their source. On the south side, deposits are composed of reddish-orange weathered schist pebbles-to-coarse sandy matrix, deriving from the schist basement (SE Qal descriptions in Table 1). On the north side, deposits are composed of Miocene volcanic clasts ranging from boulder-to-cobble size, and a grayish-brown fine sandy matrix (NE Qal descriptions in Table 1). Detailed sedimentological and morphological descriptions of fan units are described in Table 1.

My limited number of sample ages (^{14}C in Table 2; IRSL in Table 3) from the north side in Cañada del Medio suggest that NE Qal 2 is 23.51 ± 3.10 ka, NE Qal 3 is 8 ± 1 ka, and NE Qal 4 is 0.75 ± 0.25 ka. I collected four charcoal samples in the NE Qal 3 unit (Table 2;

samples SCR2501, SCR2502, SCR2508, and SCR 2513), and one IRSL sample (USU-4818; preliminary results in Table 3). Two of the four charcoal samples from NEQal 3 (SCR2502 and SC2508) yielded young ages of ~2 ka and ~3 ka, and the other two yielded ages of ~7 and ~9 ka. My IRSL age for NE Qal 3 yielded a much older age of 20.44 ± 3.06 ka. I also collected one IRSL sample in NE Qal 2 on the western side of the Cañada del Medio segment, which yielded 23.51 ± 3.10 . On the south side of the valley, SE Qal 2 has a radiocarbon age of 4.3–4.4 ka (n=1).

3.2. Christi segment

Similar to the north side of the Central segment, I identify four distinct relative ages of alluvial deposits in the Christi area, which I label from oldest to youngest as Ch Qal 1–Ch Qal 4 (Fig. 3C). The oldest unit (Ch Qal 1) is generally ~30 m higher in elevation relative to all younger deposits (Ch Qal 2 or younger) suggesting that the Qal 1 unit is much older, while Qal 2–Qal 4 cluster closer together in elevation (Fig. 6). The oldest deposits (Ch Qal 1) are composed of large (often ~0.5 to 0.1 m) angular-to-sub rounded volcanic boulders and cobbles, often covered in lichen. I interpret Ch Qal 1 deposits to be remnants of old, dissected alluvial deposits, with much of the finer grained material eroded out with only boulders and cobbles remaining (Fig. 8D & 8E). Units Ch Qal 2–4 have relatively smoother surfaces and are inset between the dissected Ch Qal 1 units. These are generally matrix-supported, which I interpret to be reworked material from older fan surfaces, except for locations proximal to the mountain front where large, clast-supported deposits occur in Ch Qal 2.

Radiocarbon samples SCR2515 and SCR2516 suggest that the upper ~2 m of the extensive fluvial deposits (Qf2) in the Christi segment date to 1.3–2.2 ka. This unit fills the large modern channels on the south side of the SCIF, and tends to be ~1-3 m thick in these smaller ~north-south trending channels. SCR2514 (317-472 yrs) also came from this deposit, but it was collected from the unconformity between the modern soil and the top of the Qf2 deposit. Sample SCR2512 came from the distal portion of the second oldest alluvial deposit in the Christi valley (Ch Qal 2) and yields an age of 28—39 ka.

The Christi segment has higher local relief than Cañada del Medio, which likely leads to differences in erosion and deposition rates between the two study areas. Due to these differences, along with my limited age constraints, I do not attempt to correlate Qal unit ages across the two study areas.

3.3. Offset along the Santa Cruz Island Fault

Between both study areas, I measured a total of 75 lateral displacements and 6 vertical displacements along the fault. Preserved lateral fault offsets vary in displacement along-strike in both study areas, from meters to hundreds of meters, as shown in Figure 9. The channels with the largest offsets are typically incised into Qal 1 surfaces, with offset measurements that cluster between ~250–650 m along the westernmost ~3 km of the terrestrial SCIF (Fig. 9, blue dots in left panel), and ~160-370 m at the easternmost end of the Cañada del Medio segment (Fig. 9, blue dots in right panel). Relatively small (meters-to-tens of meters) offsets are more often preserved in the Cañada del Medio segment where Qal 2 the most extensive Quaternary unit. Most channels that are incised into NE Qal 2 have < 50 m displacements, with many values ranging 3-20 m (Fig. 9, yellow dots). Channels

incised into bedrock have variable offsets ranging from ~3–150 m (Fig. 9, green dots), as alluvium does not deposit everywhere along the fault and some segments have complex strands that offset channels in the volcanics, north of the main fault.

For vertical displacement, six topographic profiles spaced ~20 m apart along a fault scarp that cuts NE Qal 2 (two profile examples shown in Fig. 10) yield a displacement range of 0.2–1.8 m, and an average of 0.9 m of vertical displacement across a ~150 m long segment.

Finally, I calculated cumulative offset probability density (COPD) for all lateral measurements in both study areas that are less than or equal to 20 m ($n=35$) to estimate the number of surface rupturing events that are recorded in the Quaternary units. There are three prominent peaks in the data (Fig. 11). In order of highest to lowest peak, they occur around ~3 m, ~5 m, and ~8 m.

3.4. IRSL age and uplift rates for T2 near Forney Cove

The second marine terrace (T2) has previously been correlated to offset Quaternary units along the fault. To test this assumption, I collected one IRSL sample (USU-4821; field photos shown in Fig. 12) from the outer edge exposure near Forney Cove, 14 m above modern sea level. This sample yielded a depositional age of 232.91 ± 13.10 ka, which is associated with the MIS 7 sea level highstand. In a shoreline perpendicular profile (Fig. 13) I show the range of possible inner edge elevations using the projected exposure of the marine terrace platform as the minimum elevation estimate (29 m), and the location where an increase in topographic roughness and steepness as the maximum elevation estimate (40 m), consistent with previous work (Pinter et al. 1998a; 2003; Muhs et al. 2021).

Relative sea level (RSL) for MIS 7 along the southern California coast is poorly constrained, and the resolution of the IRSL age allows the terrace to potentially derive from any substage from MIS 7, causing further RSL and uplift rate uncertainties. Global sea level reconstructions based on locations where glacio-isostatic effects are expected to be relatively small (e.g., Spratt & Lisiecki, 2016; Siddall et al. 2003) suggest that eustatic sea level was near or below present mean sea level during MIS 7 highstands. Assuming RSL was near present, our data yields uplift rates of 0.15 ± 0.05 m/ka. This is a conservative estimate, as uplift rates are higher if RSL was lower than present day mean sea level.

4. Discussion

New mapping, geochronology, and offset measurements provide improved constraints for Quaternary deformation along ~13 km of the Santa Cruz Island Fault, including the ages of Quaternary deposits, maximum displacement per event, and minimum estimates for recurrence interval and slip rate. These results have two main implications: first, they provide the first recurrence interval and slip rate estimate from the Cañada del Medio segment. Second, our preliminary IRSL ages for marine terrace and alluvial deposits on the western side of Santa Cruz Island suggest that the age assumptions used in previous slip rate estimates should be revisited. Below, I discuss Quaternary unit ages, controls on offset preservation, displacement per event, recurrence interval, and slip rates for both study areas.

4.1. Relative and absolute ages: Cañada del Medio

Combined ^{14}C and IRSL data from this study suggests that the Quaternary units along and near the fault range from late Pleistocene to Holocene. Based on my collective age

constraints for Quaternary alluvial and fluvial deposits, for the northern Cañada del Medio segment these data suggest that NE Qal 4 is 1–0.5 ka, SE Qal 2 is ~4.4 ka, NE Qal 3 is 9–7 ka, NE Qal 2 is 20.4–26.6 ka, and I have no age constraints for Qal 1 for the north or south side of the valley. At Christi, the upper ~2 m of the Qf2 deposits date to 1.3–2.2 ka, and Ch Qal 2 is 76.5–102.7 ka. I do not have age constraints for Ch Qal 1, Ch Qal 3, or Ch Qal 4.

I have the most age constraints for NE Qal 3 on the eastern side of Cañada del Medio. My ^{14}C estimates NE Qal 3 to be deposited during the Holocene, with ages of ~3, ~7 and ~9 ka, while IRSL suggests a late Pleistocene depositional age of ~20 ka. I suggest that the older two ^{14}C samples (SCR2501 and SCR2513) more accurately fit the expected age of the NE Qal 3 deposit (~7 ka and ~9 ka) based on several lines of reasoning. First, the elevations relative to the modern channel and weathering characteristics of NE Qal 3 deposits suggest that it is older than NE Qal 4, which has an age range of 548—1048 (cal BP) based on two radiocarbon samples. Second, this inference is further supported by my IRSL age extracted from NE Qal 2, ~3 km west of this site, which also has an age of ~20 ka (IRSL; USU-4817). It is possible that the grain size of the NE Qal 3 IRSL sample impacted the results, as this was my only sample that was composed of very fine sand-to-silt, which can have a faster rate of transport, and therefore less bleaching time (Rittenour, 2008). All other IRSL samples were composed of medium-to-fine grain sand layers and yielded reasonable results based on their elevations and characteristics.

The SE Qal 2 age of 4.4 ka is the only age constraint for the south side of the Cañada del Medio segment and it is younger than previous studies estimated (Schmidt et al. 2019). I attempted to use radiocarbon to distinguish the relative ages (NE vs SE) across the Cañada

del Medio valley, however, detrital charcoal and sandy beds for IRSL were much less abundant on the south side, and therefore I have very little data to resolve this.

4.2. Relative and absolute ages: Christi

In the westernmost ~3 km of the Christi region, I mapped two generations of alluvial deposits (Ch Qal 1 and Ch Qal 2) overlying bedrock. Based on the homogeneous lithologic composition, clast size, and angularity of these units (Fig. 8; Fig. 14), I interpret them as mountain-front alluvial deposits derived from north of the fault, unconformably overlying uplifted bedrock. Prior slip rate estimates for this segment correlated the surface elevations of these two surfaces with the T2 and T3 marine terraces near Forney Cove, assigning them a preferred age of ~315 ka (MIS 9) and ~400 ka (MIS 11), respectively (Pinter et al., 1998a; 2003).

One radiocarbon sample from the Ch Qal 2 unit yielded 28–39 ka, which was previously estimated to be ~315 ka (Pinter et al. 1998a). For this reason, I prefer my preliminary IRSL sample (USU-4822) age of 89 ± 13 ka for this deposit. Although older than the radiocarbon date, the IRSL age is still more than 200 ky younger than previously assumed (Fig. 14). Similarly, my IRSL age from the T2 marine terrace (USU-4821) yields 232.91 ± 30.15 ka, consistent with the MIS 7 highstand, rather than MIS 9. These preliminary IRSL ages suggest that these two deposits are younger than previously assumed, and that the age of the alluvial units in Christi valley do not correlate directly with the marine terrace ages at similar elevations.

4.3. Controls on unit and offset preservation along the fault

The question arises as to why there is an order-of-magnitude variability in lateral displacement recorded along-strike, with some sections exhibiting meters of displacement, while others exhibit hundreds of meters. The two locations where the largest offset channels occur correspond with the only sites where Qal 1, the oldest deposit, is preserved (Fig. 9). The channels with the largest offsets are also some of the widest and most deeply incised. Together, these observations support an expected relationship between the age of the channel and the amount of displacement recorded in it, as the largest offsets found along the SCIF occur in the oldest channels.

The largest offsets and oldest units also correspond to locations where the fault is far from the main ~east-west trending valley channel (Fig. 15). Conversely, smaller offsets also cluster where the main channel is closest to the fault. I argue that this supports a hypothesis where offset preservation is controlled by the distance between the main fault and the main east-west river channel, which in turn controls the amount of space available for unit preservation and channel formation. For example, many beheaded channels occur >100 m from the fault, therefore, locations where the main channel is < 100 m from the main fault, the main channel limits preservation of older units and large offsets by eroding and reworking material.

4.4. Age and uplift for T2 at Forney Cove

Uplifted marine terraces are useful for constraining vertical deformation rates along faults when both the terrace age and RSL at the time of formation are known (e.g., Morel et al. 2022; Pinter et al. 1998a; Kelsey et al. 1996; 1990; Padgett et al. 2019; McKenzie et al.

2022). IRSL sample (USU-4821) from the T2 terrace near Forney Cove, which has a paleo shoreline angle 30–40 m above modern sea level (Fig. 13), yields a preliminary age of 232 ± 13.10 ka, correlating with the MIS 7 highstand. MIS 7 terraces are often poorly preserved because it was not a significantly warm interglacial (Siddall et al., 2003), leading previous authors to assign T2 to MIS 9 (~ 315 ka; Pinter et al., 1998a; 2003). This is a very wide platform (up to ~ 1 km), with relatively low uplift rates there is the possibility of reoccupation during multiple highstands, where MIS 7 represents the most recent. My uplift rate estimates of 0.15 ± 0.05 m/ka fit broadly with prior estimates by Pinter et al. (1998a; 2003) based on their T3 age estimate, but exceed those of Muhs et al. (2021) which are derived from T3 near Potato Harbor on the northeast side of the island.

4.5. Cumulative offset probability density

The COPD shows three modal peaks at ~ 3 m, ~ 5 m, and ~ 8 m, which I interpret as reflecting a minimum of three discrete surface-rupturing earthquake events recorded in offset channels along the Santa Cruz Island Fault (e.g., Salisbury et al., 2012; Zielke et al., 2012). My dataset of measured offsets that are < 20 m is limited to 35 data points, therefore, modal peak values should be considered at the meter-scale resolution. The tallest peak at ~ 3 m is in agreement with the lower end of the 3–4 m displacement per event estimated by Patterson (1979), and the clustering of small, similar-sized (~ 3 m) offsets in relatively young deposits in the western Cañada del Medio segment (Fig. 9) further supports ~ 3 m as the maximum displacement during the most recent surface-rupturing event. However, I interpret the ~ 3 m peak to represent a maximum displacement value rather than precise slip-per-event estimates because studies have shown that in regions where earthquake recurrence exceeds

the rate of channel formation, even the smallest offset channels may preserve cumulative displacement from multiple events, leading to overestimates of slip-per-event (Zielke et al., 2010).

4.6. Quaternary slip at Cañada del Medio

To estimate a recurrence interval, I rely on channels A93 and A96 (Fig. 10), which are incised into a NE Qal 2 deposit near my IRSL sample site (USU-4817; 23.51 ± 3.10 ka). Because the deposit predates the channels, I estimate an open interval slip rate and recurrence interval are minimum bound estimates. Channel A93 displays 9.8–13.7 m of left-lateral displacement (mean 11.0 m), and channel A96 records 7.0–11.6 m of displacement (mean 8.7 m). The difference in mean displacement between the two channels likely reflects differences in channel age rather than slip rate. A96 is narrower, shallower, and has better-preserved piercing points than A93, suggesting A96 is younger than A93, therefore, it has likely experienced fewer earthquake events.

Assuming a maximum of ~ 3 m of displacement per event (see Section 4.5), both channels record a minimum of three surface-rupturing earthquakes since their formation. Assuming the IRSL age approximates the timing of channel formation, these offsets yield a minimum recurrence interval of 7.5 ± 1.5 ky and a lateral slip rate of 0.5 ± 0.2 m/ka. The recurrence interval and slip rate may be higher if (1) channels are significantly younger than the deposit, (2) additional active strands in this area accommodate slip that is not recorded at this site, and/or (3) displacement per event is less than ~ 3 m. Pinter et al. (1998a) estimated a recurrence interval of 5 ky and a minimum open interval slip rate of 0.8 m/ka in the Christi valley, which is largely consistent with my results for Cañada del Medio considering I am reporting minimum bounds.

4.7. Re-evaluating the slip rate at Christi Beach

My geochronological constraints are limited with respect to estimating a slip rate using the offset channels in Christi valley. However, my new results and inferences on the origins of the alluvial deposits within the Christi valley have implications for the methods used in previous slip rate estimates on the Santa Cruz Island Fault. First, my mapping suggest the offset features previously used to estimate a slip rate as remnants of mountain-front alluvial deposits, rather than fluvial terraces. Second, my preliminary IRSL age for Ch Qal 2 (89 ± 13 ka) is ~ 200 ka younger than previously assumed, and my preliminary IRSL age from marine terrace T2 (232 ± 30 ka) is ~ 100 ka younger than expected. Third, the age differences between these alluvium and marine terrace deposits suggest that the elevation correlation method in Pinter et al. (1998a) may not be a reliable way to constrain the age of the offsets in the Christi valley. For these reasons, I argue that the slip rate for the Santa Cruz Island Fault requires more geochronology to estimate a reliable slip rate.

5. Conclusions

New mapping, geochronology, and offset measurements along ~ 13 km of the Santa Cruz Island Fault provide new constraints with direct implications for seismic hazard in southern California. I identify up to 4 alluvial fan generations in both study areas ranging in age from ~ 0.5 – 100 ka. My COPD of 35 lateral offset measurements yields three distinct peaks interpreted to represent three surface-rupturing earthquakes, which likely had a maximum displacement of ~ 3 m. I estimate a minimum recurrence interval of 7.5 ± 1.5 ky and

minimum lateral slip rate of 0.5 ± 0.2 m/ka for the Cañada del Medio segment. My IRSL ages for alluvial deposits in the Christi valley and the T2 marine terrace at Forney Cove indicate these deposits are substantially younger than previously assumed, and my mapping suggests the units previously used to constrain the slip rate estimate have a different origin than interpreted by previous authors. My preliminary T2 age of 232 ± 13 ka is consistent with the MIS 7 highstand and yields a minimum uplift rate of 0.15 ± 0.05 m/ka for the western end of the island. I also find that offset preservation along the SCIF is controlled primarily by the distance between the fault and the main valley channel, such that older deposits and larger offsets are preserved where the channel is furthest from the fault. Additional geochronology is needed to estimate a reliable slip rate for the full length of the terrestrial Santa Cruz Island Fault.

Appendix

Tables

Table 1. DESCRIPTIONS OF QUATERNARY ALLUVIAL FANS IN THE CHRISTI AND CAÑADA DEL MEDIO STUDY AREAS OF SANTA CRUZ ISLAND.

Unit	Description
Qal 1 (Ch & NE)	Thin, eroded remnants of alluvial fans that have likely not experienced deposition for tens to hundreds of thousands of years. These surfaces are found at the highest elevations relative to all other alluvial fans, typically 20–50 m above the modern valley channel. These units tend to be poorly sorted, consisting of pebble-to-boulder sized clasts, which coarsen from the mid- to proximal fan. Lichen-covered, boulder-to-cobble sized angular-to-sub angular volcanic clasts are found at the surface. Within Cañada del Medio, these thin surfaces sit stratigraphically on top of SCI Volcanics, and at Christi Beach they drape over schist and/or mafic-to-felsic intrusive rock.
Qal 2 (Ch & NE)	Extensive throughout the study area, especially in Cañada del Medio, and likely have not experienced deposition for tens of thousands of years (likely late Pleistocene). Found inset into some Qal1 units, at relatively lower elevations than Qal1, but are otherwise relatively higher than all other Qal units. These surfaces range from several meters up to ~30 m above adjacent modern channels. These units may be matrix or clast-supported by SCI volcanics and sandy, cross-stratified beds are exposed in the main central valley channel at the mid- to distal fan segments. The deposits tend to be sandy-brown in color. Their high degree of clast weathering can lead to “ghost clasts.” These are moderately to well compacted. These surfaces are covered in grasses and tend to be relatively steeper than younger Qal surfaces, and tend to be meters to tens of meters above modern and recently active channels.

Qal 3 (Ch & NE)	Less extensive than Qal2 throughout the study area and likely abandoned for thousands of years (early Holocene?). Inset into Qal2, and often channelized by modern to recently active channels. These surfaces tend to have higher vegetation density due to vertical proximity to modern channels. The units are moderately compacted. Deposits are matrix or clast-supported, and contain sub-angular to sub rounded clasts composed of weathered SCI volcanics, which increase in size at the proximal segment. Small cobble to silt layers are common in the mid- to distal fan. These deposits are often brownish-grey in color. There is an unconformity between the fan deposits and modern soil horizon.
Qal 4 (Ch & NE)	Relatively low in elevation, and typically incised into Qal3. Intermediate to loose compaction, with a mixture of highly weathered and relatively less weathered volcanics. Modern to hundreds of years old. The deposits are brownish grey in color. Since these are often distant from the mountain fronts, they tend to have smaller grain size than all older alluvial fans, and are often loosely compacted with highly weathered grains, which were likely mobilized out of older fans and reworked into these younger deposits. Interbedded alluvium and trough cross bedding are found at the distal portions of the fan, where the alluvial deposits interact with the main channel. These units are often a combination of fluvial deposits deriving from the main channel as it migrates within the valley, and alluvial deposits coming from upslope to the north, depending on proximity relative to the mountain front. No evidence of deformation was found in Qal 4 units.

Qal 1 (SE)	These deposits tend to be ~20–30 m above the modern main central valley channel. Their topography is often rounded and subdued, and grade into the mountains to the south side of the eastern central valley. They were likely abandoned tens of thousands of years ago. Matrix and clasts within these deposits are highly weathered, as they derive from pre-Jurassic schist, and the matrix is often varying shades of red. The clasts are sub angular to sub rounded, and the deposits are well compacted. Grasses cover the surfaces.
Qal 2 (SE)	These deposits are inset into SEQal1, and are often found 5–10 m above modern adjacent channels. These deposits tend to have relatively small (1–3 m width) channels incised into them.
Qal 3 (SE)	These deposits are modern to hundreds of years old, and are likely equivalent in age to NEQal4 on the north side of the central valley, as they are found at the same relative elevations and interact with the modern central valley channel. No evidence of deformation was found in SE Qal 3.

Table 2. RADIOCARBON DATA FROM DETRITAL CHARCOAL COLLECTED FROM QUATERNARY ALLUVIAL AND FLUVIAL DEPOSITS IN THE CHRISTI AND CAÑADA DEL MEDIO STUDY AREAS ON SANTA CRUZ ISLAND

UCIAMS #	Sample name	Unit	$\delta^{13}\text{C}$ (‰)	$\pm$	D^{14}C (‰)	$\pm$	^{14}C age (BP)	Calibrated range (CalBP)
311469	SCR2401	Qal4 North	0.8763	0.0015	-123.7	1.5	1060 $\pm$ 15	1048–946
311478	SCR2511	Qal4 North	0.9286	0.0014	-71.4	1.4	595 $\pm$ 15	641–548
311470	SCR2501	Qal3 North	0.3722	0.0007	-627.8	0.7	7940 $\pm$ 20	8983–8641
311471	SCR2502	Qal3 North	0.7306	0.0011	-269.4	1.1	2520 $\pm$ 15	2725–2501
311480	SCR2513	Qal3 North	0.4738	0.0008	-526.2	0.8	6000 $\pm$ 15	6895–6750

311476	SCR2508	Qal3 North	0.6913	0.0011	-308.7	1.1	2965 ± 15	3208–3070
311477	SCR2509	Qal3 North	0.9819	0.0015	-18.1	1.5	145 ± 15	278–0
311479	SCR2512 (0.017mgC)	Qal2 North	0.0343	0.0094	-965.7	9.4	27100 ± 2200	39494–27645
311472	SCR2503 (reburn of 155274)	Qal2 South	0.9783	0.0015	-21.7	1.5	175 ± 15	286–0
311474	SCR2505	Qal2 South	0.6133	0.0011	-386.7	1.1	3925 ± 15	4420–4293
311475	SCR2506	Qal2 South	0.9821	0.0015	-17.9	1.5	145 ± 15	278–0
311473	SCR2504	Qal2 South	0.9796	0.0017	-20.4	1.7	165 ± 15	285–0
311481	SCR2514 (0.18mgC)	Qfluvial2 North	0.9579	0.0015	-42.1	1.5	345 ± 15	472–317
311486	SCR2515	Qfluvial2 North	0.8297	0.0013	-170.3	1.3	1500 ± 15	1400–1347
311487	SCR2516	Qfluvial2 North	0.7681	0.0012	-231.9	1.2	2120 ± 15	2146–2002

Locations for each sample shown in Fig. 2. Radiocarbon data provided by UC Irvine.

*Radiocarbon concentrations are given as fractions of the Modern standard, $\delta^{14}\text{C}$, and conventional radiocarbon age, following the conventions of Stuiver and Polach (Radiocarbon, v. 19, p.355, 1977). Note: for $\Delta^{14}\text{C}$, see the Stuiver and Polach reference. Sample preparation backgrounds have been subtracted, based on measurements of ^{14}C -free wood. All results have been corrected for isotopic fractionation according to the conventions of Stuiver and Polach (1977), with $\delta^{13}\text{C}$ values measured on prepared graphite using the AMS spectrometer. These can differ from $\delta^{13}\text{C}$ of the original material, and are not shown. Comments: These samples were treated with acid-base-acid (1N HCl and 1N NaOH, 75°C) prior to combustion. The SCR2507 and SCR2510 samples were too small and could not be measured. The large uncertainty for the SCR2512 sample is due to a combination of small sample size and age.

Table 3. POST INFRARED-INFRARED STIMULATED LUMINESCENCE AGES (PRELIMINARY) COLLECTED FROM QUATERNARY ALLUVIAL FANS AND MARINE TERRACES ON SANTA CRUZ ISLAND.

USU#	Sample name	Unit	Age±2SE (ka)	Burial depth (m)	Elev (m)	# aliquots*	Lat/long
4817	SCR2401	NE Qal 2	23.51±3.10	3.00	98	14(17)	34.003489, - 119.745583
4818	SC2501	NE Qal 3	20.44±3.06	1.16	83	13(17)	33.996242, -119.710017
4819	SC2502	Qal 4 NE	NA	1.14	60	12(17)	33.996583, -119.714494
4820	SC2503	Marine terrace T1 (north)	NA	3.7	5	2(8)	34.062325, -119.919306
4821	SC2504	Marine terrace T2 (north)	232.91±30.15	4.2	14	13(17)	34.063264, -119.917872
4822	SC2505	Ch Qal 2	89.58±13.10	1.34	46	10(15)	34.021036, -119.862617
4823	SC2506	Marine terrace T1 (south)	NA	5.6	10	8(9)	33.977456, -119.8614
4824	SC2507	Qal 2 Ch	NA	2.8	101	0(9)	34.021789, -119.846919

Locations for IRSL samples shown in Fig. 2. *Number of aliquots used in age calculation and number of aliquots analyzed in parentheses. Luminescence measurements were made using the single-aliquot regenerative-dose procedure of Wallinga et al. (2000) on 2 mm small aliquots of feldspar sand at 50 °C IRSL.

Figures

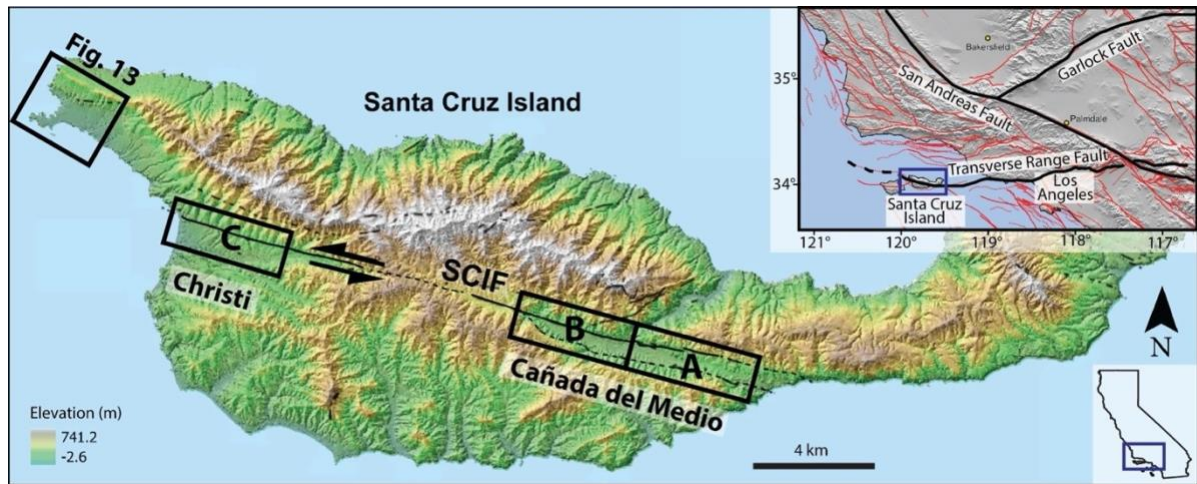


Figure 1. Inset map (modified from Plesch et al. 2007) shows the location of Santa Cruz Island and the Santa Cruz Island Fault (SCIF) with respect to Los Angeles, CA, as well as major known faults in the Los Angeles region (black), with relatively smaller faults shown in red. The zoom in is a map of Santa Cruz Island, California, from a 1-m digital elevation model (DEM) overlaying hillshade (USGS, 2010). The main Santa Cruz Island Fault (SCIF, black) is based on mapping in Schmidt et al. (2019), with arrows indicating relative lateral motion across the fault. The black rectangles labeled Cañada del Medio (A & B) and Christi (C) indicate the areas of focus for this study. Zoom-ins showing geologic mapping of these areas are in Fig 3.

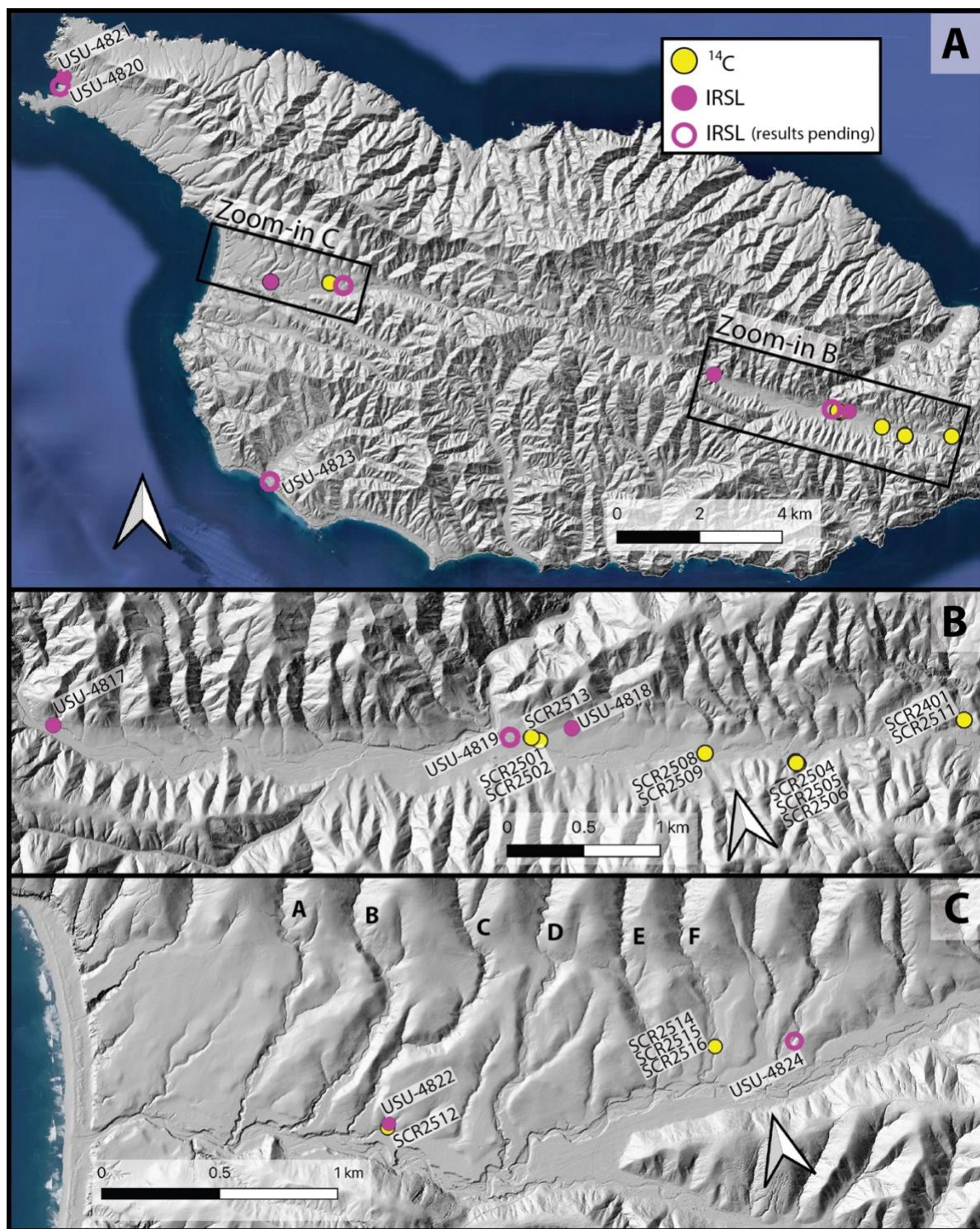


Figure 2. 1-m DEM-derived hillshade (USGS, 2010) showing sample locations for dating. (A) shows an overview of the main fault study areas on Santa Cruz Island with black rectangles to indicate the locations of zoom-ins B & C. Marine terrace sample sites are also shown in (A). (B) shows the entire Cañada del Medio study area, and (C) shows the Christi study area. Yellow = charcoal sample site, pink filled dot = IRSL site with preliminary

results, and pink hollow dot = IRSL site with pending lab results. Channels labeled A–F show the left lateral offsets measured in Pinter et al. (1998a) to estimate slip rate.

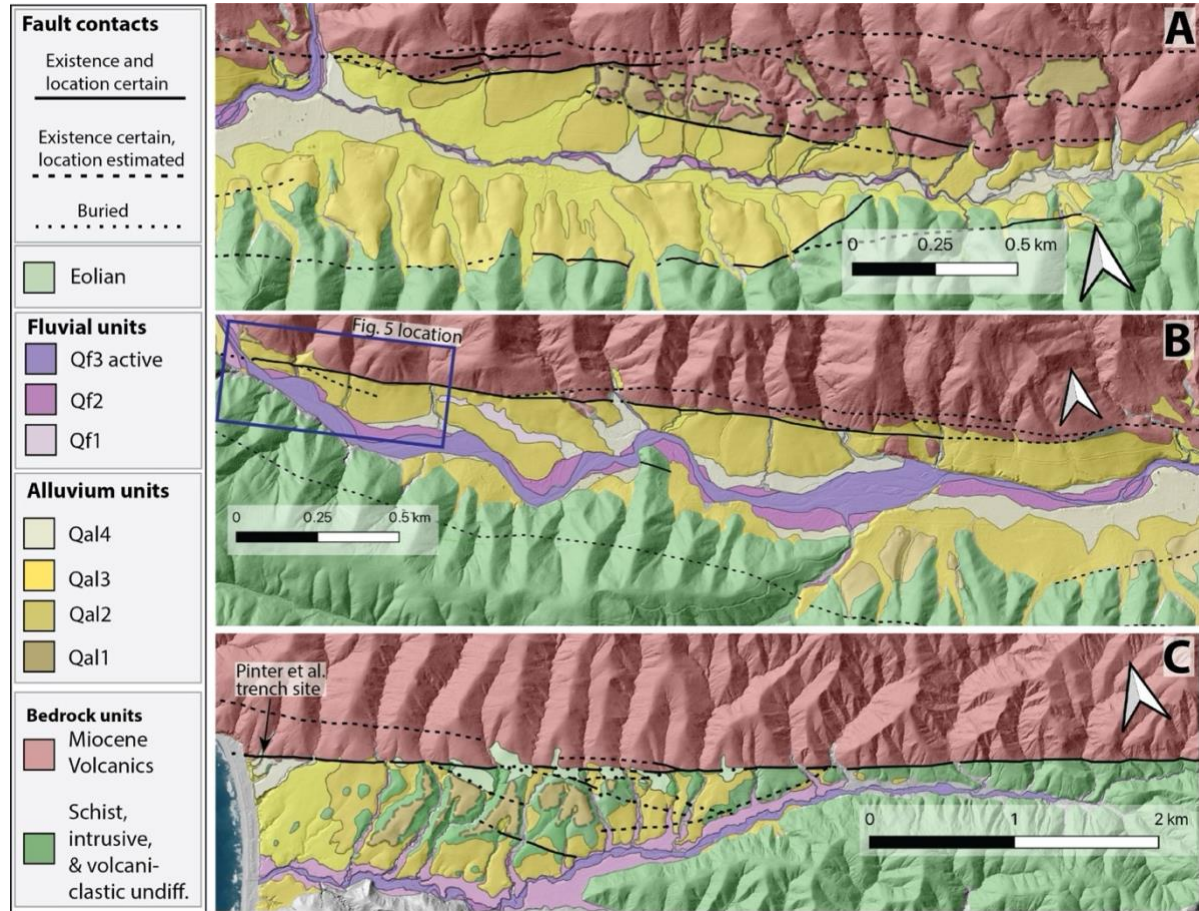


Figure 3. Geologic mapping overlaying hillshade of the areas of focus for this study (locations shown in Fig. 1). (A) shows the eastern side of the Cañada del Medio segment, (B) shows the western side of the Cañada del Medio segment, and (C) shows the Christi segment. Qal units are categorized relative to their segment and should not be assumed to be the same age across segments. Similarly, the opposing north and south Qal units within the Cañada del Medio segment shown in (A) & (B) are not assumed to be the same age, but rather, they are relative to their own side of the valley (“NE” Qal units are the north side of the valley for (A) and (B); “SE” Qal units are the south side of the valley in (A) and (B); “Ch” Qal units are all Quaternary units shown in (C)) Location of trench site from Pinter et al. (1998a) indicated in (C). Faults are shown in black solid and dashed lines to indicate certainty, and dotted where buried by younger units. Dashed lines around Quaternary alluvial units are used in areas where anthropogenic activity has modified the land surface and obscured alluvial contacts, such as at the Santa Cruz Island Chapel (Lat./long: 33.997106, -119.714064), or when the contacts between bedrock and coarse abandoned alluvial deposits are not precisely located.

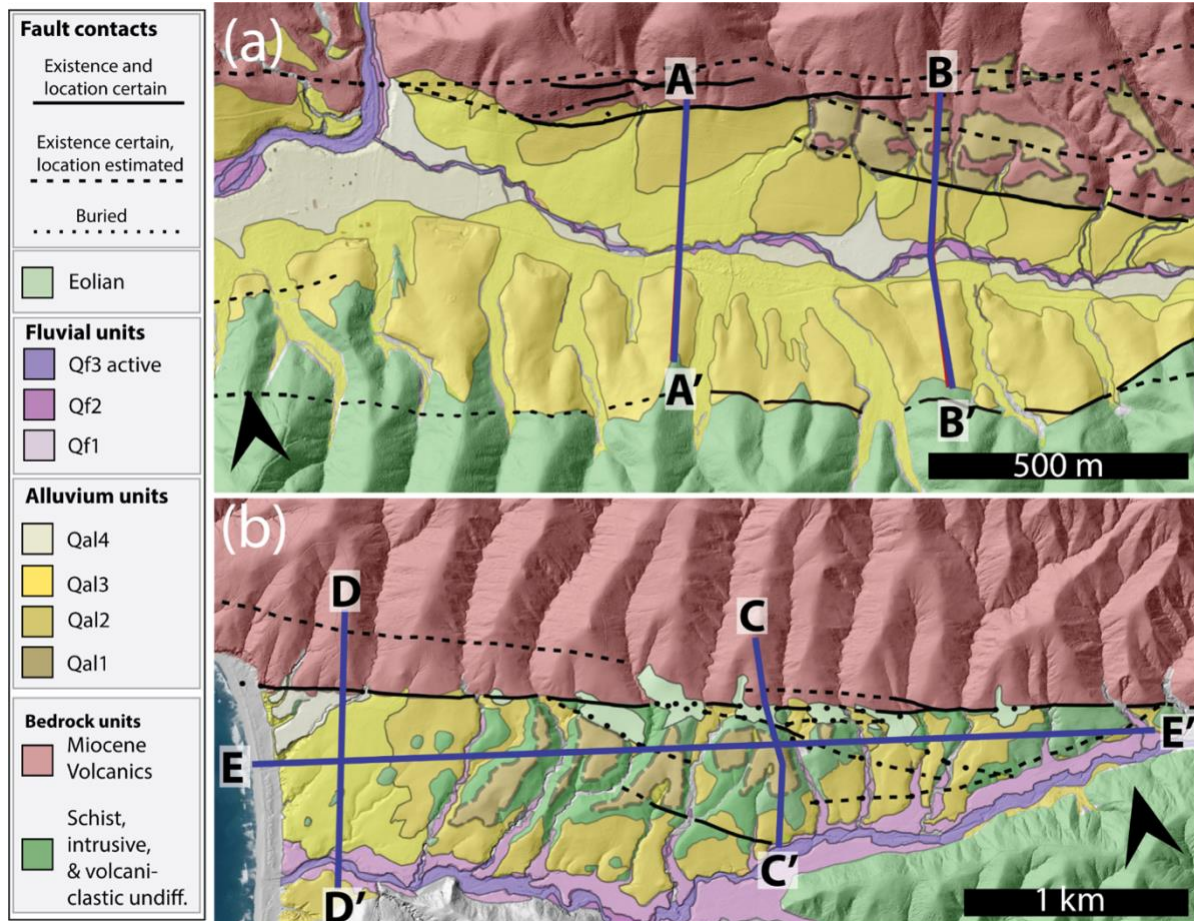


Figure 4. Zoom-ins of surficial geologic maps overlaying hillshade derived from 1-m DEM (USGS, 2010) of (a) the eastern side of the Cañada del Medio segment, and (b) the Christi segment showing locations of cross sections. Dark blue lines show locations of cross sections A–B (Fig. 5) and C–E (Fig. 6).

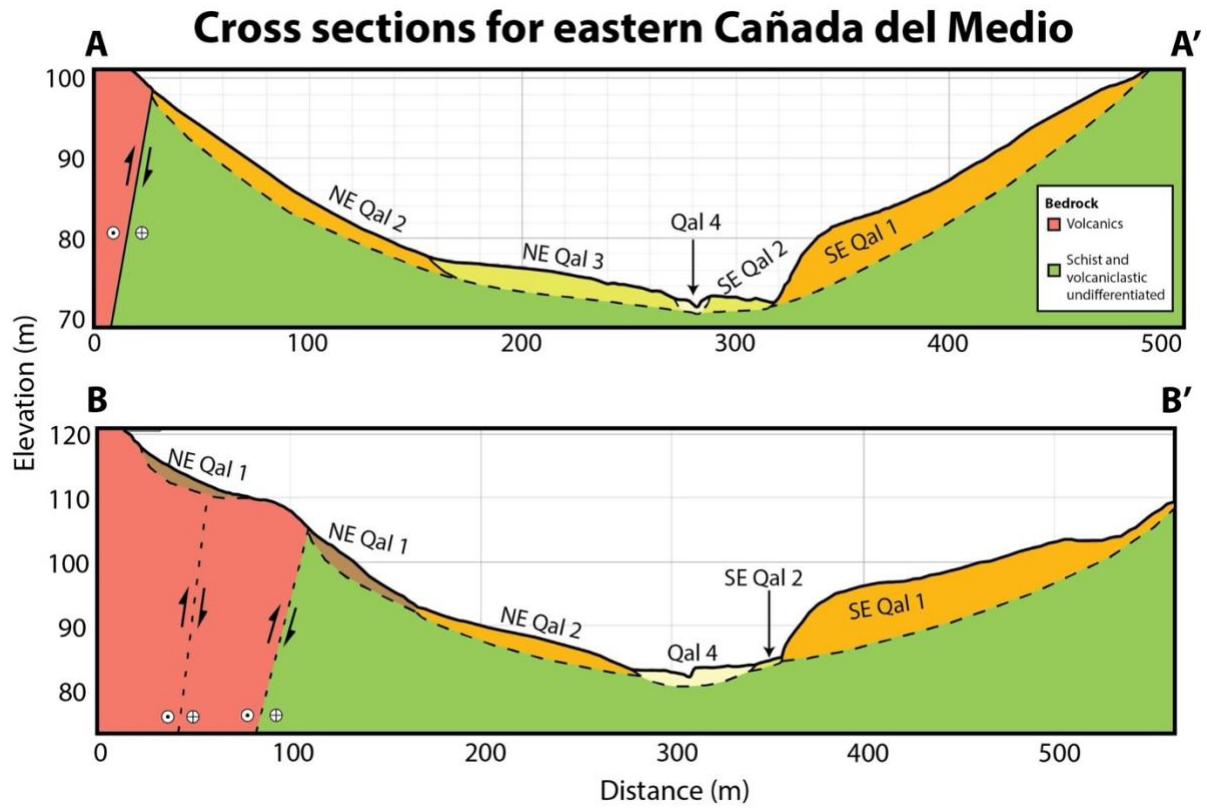


Figure 5. Cross sections in the Cañada del Medio study areas to show relative elevations of surficial units. Locations shown in Fig. 8a. For both cross sections, the SCIF juxtaposes SCI Volcanics to the north, and basement to the south of the fault.

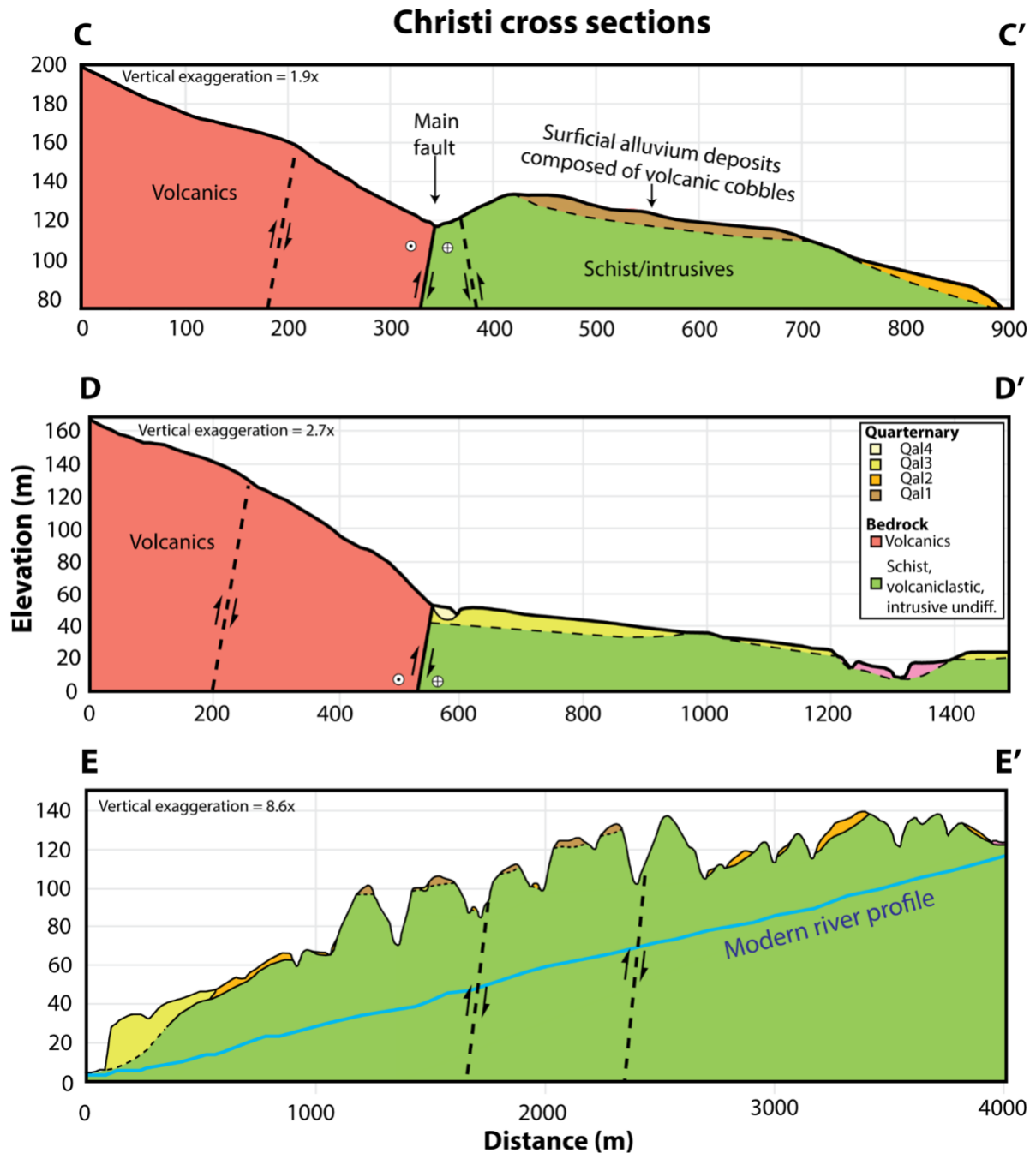


Figure 6. Cross sections in the Christi study area to show relative elevations of surficial units. Locations shown in Fig. 8B. E–E' shows the SCIF juxtaposing SCI Volcanics to the north, and basement to the south of the fault. Abandoned Ch Qal 1 alluvial deposits composed of volcanic cobbles and boulders overlie basement rock, which were previously mapped in Pinter et al. (1998a) as fluvial deposits. Photos of surficial Qal 1 deposits are shown in Fig. 4d, 4e, and Fig. 13. D–D' shows the same, but for a younger alluvial unit (Ch Qal3) at the westernmost end of the study area. (C) shows an ~east-west cross section that highlights the elevations for the three oldest alluvial units relative to the modern river profile. Qal 1 is up to ~70 m above the modern channel, while Qal 2 or younger tends to be

~40 m or less above the modern channel, indicating that Qal 1 is much older than the other units.

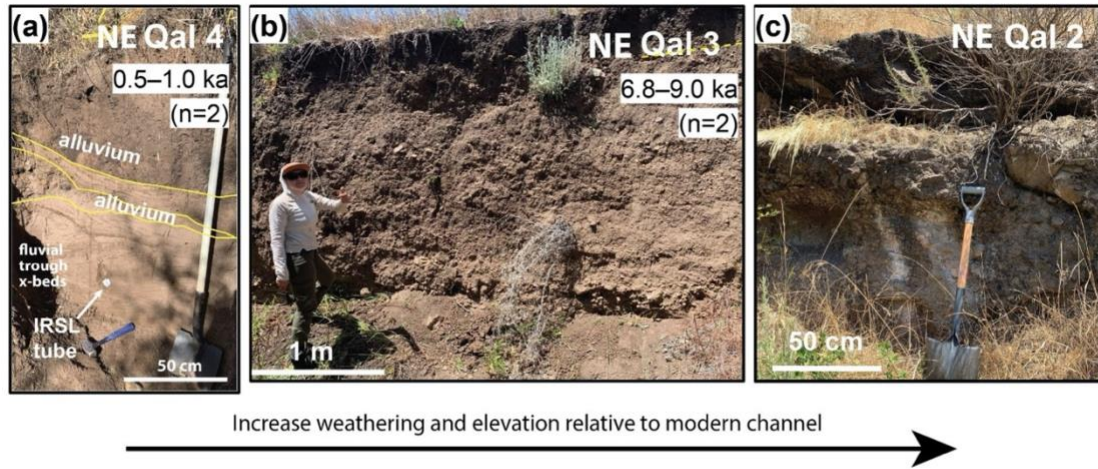


Figure 7. Field photos showing relative weathering and characteristics of Quaternary alluvium units on the north side of the Cañada del Medio valley. Detailed descriptions are provided in Table 1. (a) shows unit NE Qal 4 and IRSL sample site for SCI2502 on the north side of the valley, ~70 m south of the chapel, at 33.996648, -119.714525. (b) shows NE Qal 3 at 33.995978, -119.712442. (c) shows NE Qal 2 on the north side of the valley at 33.992167, -119.693369.

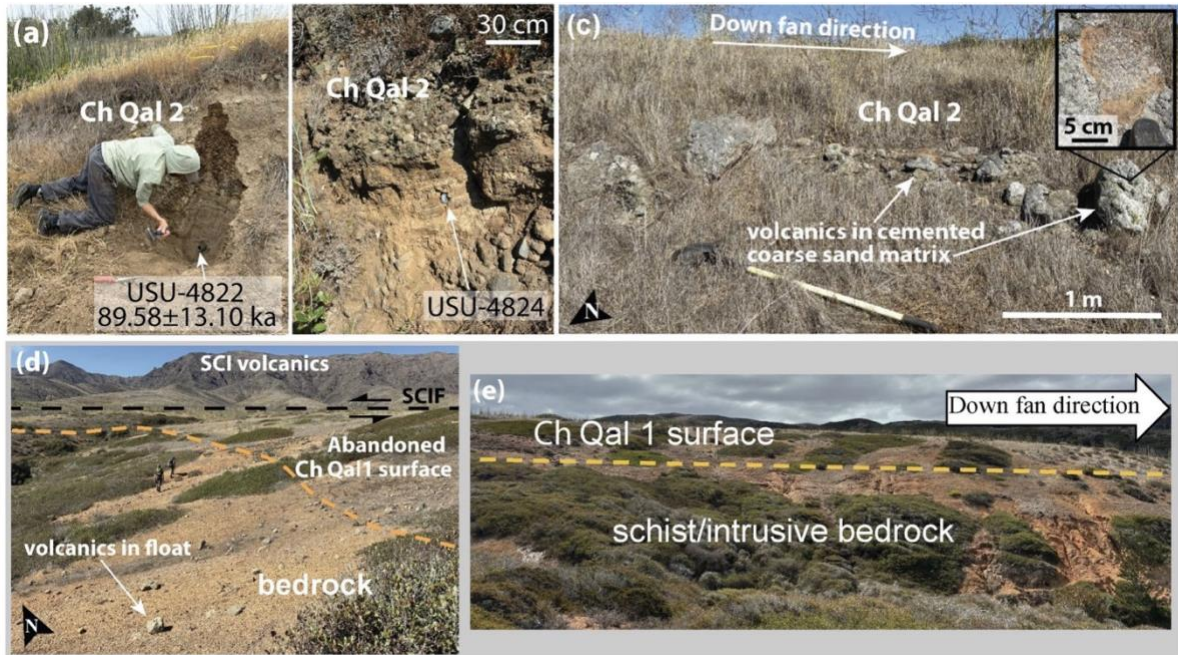


Figure 8. Field photos of Ch Qal 1 and Ch Qal 2 in the Christi study area. (a), (b) and (c) are examples of Ch Qal 2 located at 34.020723, -119.843346, 34.003573, -119.745721, and 34.0215883, -119.8419135, respectively. (d) and (e) are two perspectives of the same Ch Qal 1 surface located at 34.0222494, -119.8518736.

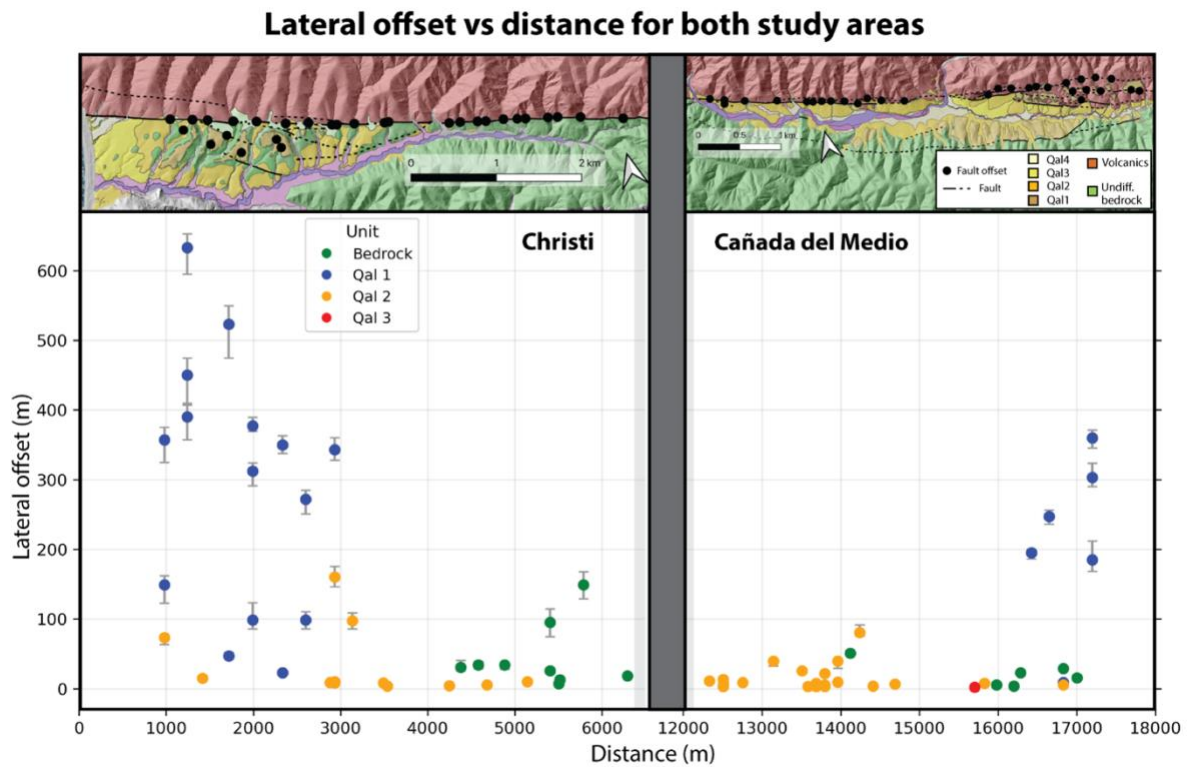


Figure 9. Scatterplot showing distance along-strike (x-axis) vs lateral displacement (y-axis) for 75 fault offset measurements in both study areas. The region between ~6500-12000 m was not analyzed in this study. Dots are color-coordinated by the unit that the offset channel

has incised into, providing a relative age proxy for displacement. Displacement locations (black dots) shown above on 1-m resolution bare earth hillshade maps overlain by geologic units (detailed geologic maps from Fig. 2).

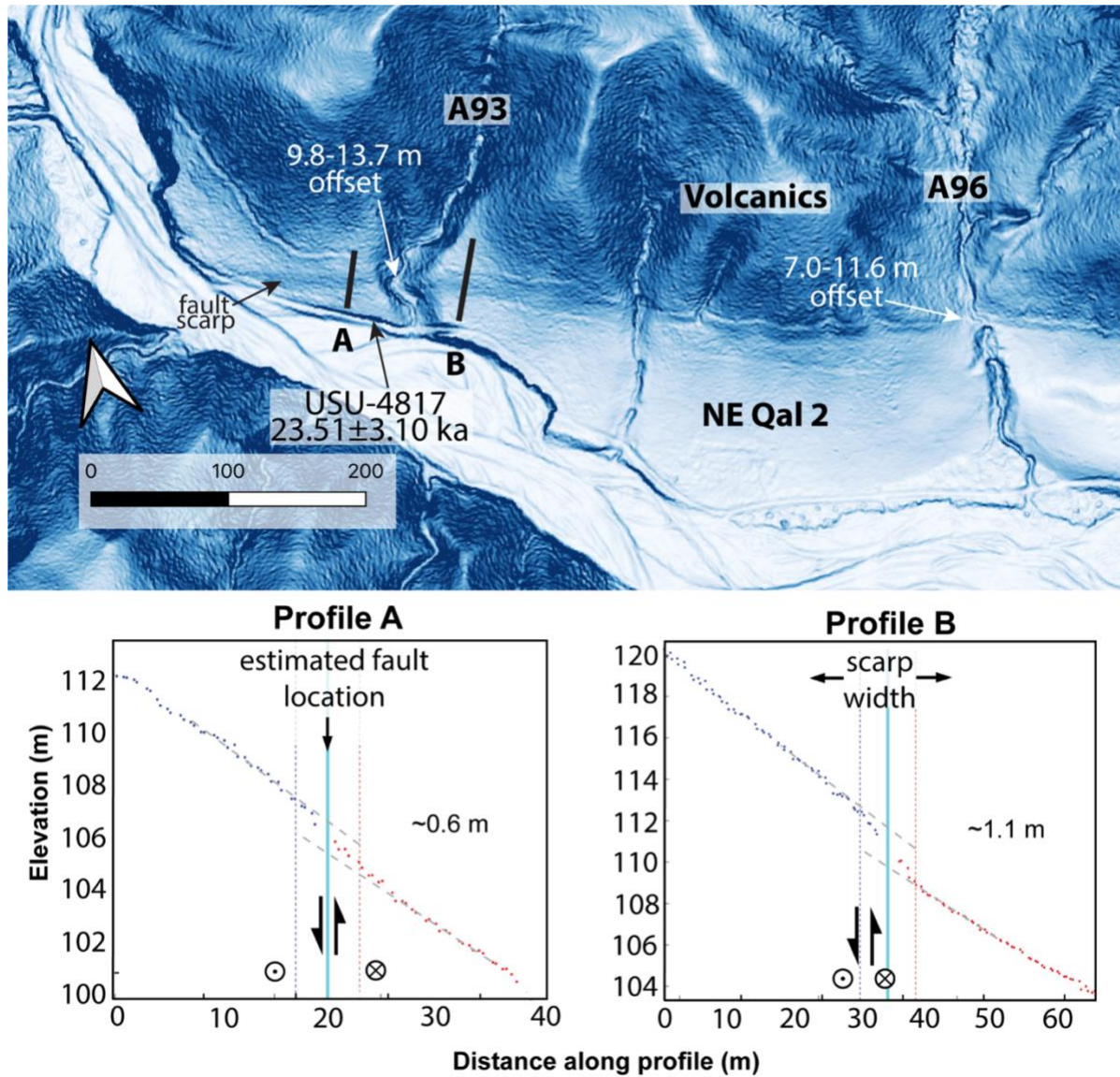


Figure 10. DEM-derived slope map (location shown in Fig. 3B) showing the IRSL sample site (USU-4817, black arrow) from NE Qal 2. Locations for channels A93 and A96 and their respective lateral offsets are shown with white arrows. Profiles A and B (black lines) show the location of fault scarp profiles A and B, drawn across unit NE Qal 2 (mapping shown in Fig. 3B). Mean vertical displacement for each profile is listed on each profile. Gray lines show projected undeformed alluvial slopes to show the vertical displacement, assuming that these features had a constant slope gradient prior to any earthquake events.

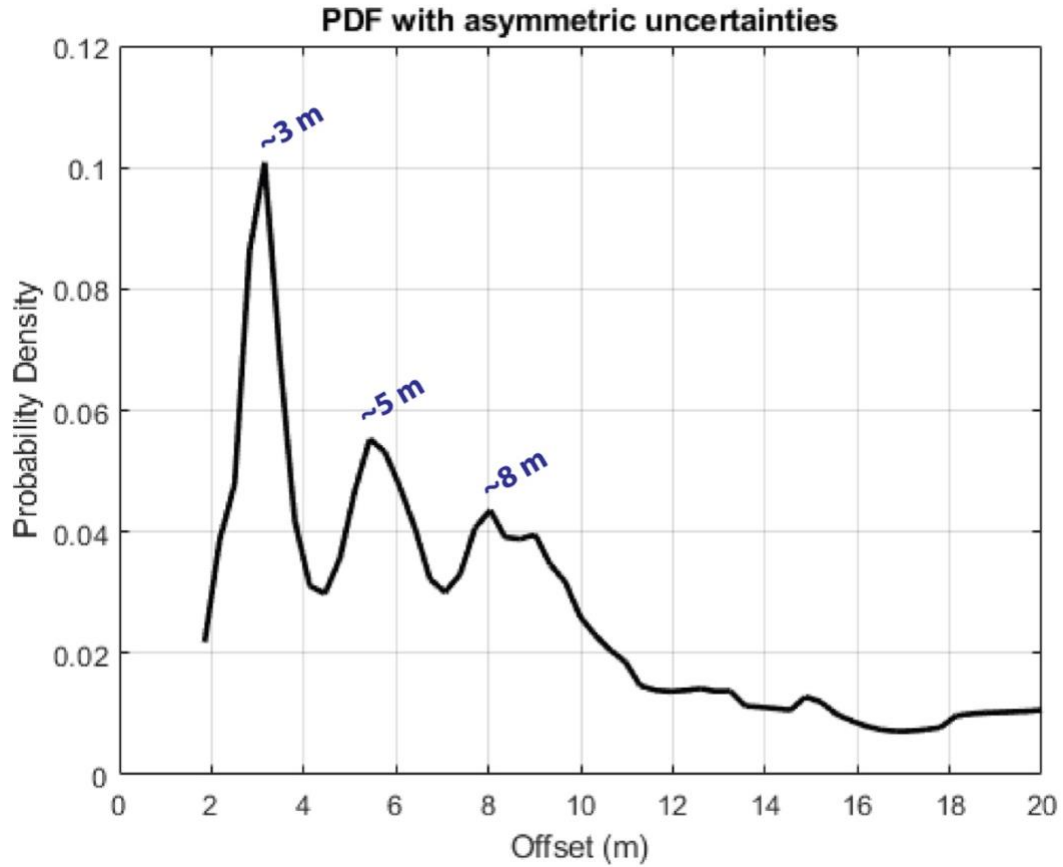


Figure 11. Cumulative offset probability density (COPD) for lateral offsets equal to 20 m or less from both study areas along the Santa Cruz Island Fault. Each offset measurement is represented as an asymmetric probability density function using individual uncertainty bounds. Peaks occur around ~3 m, ~5 m, and ~8 m, representing clusters of similarly sized offset measurements.

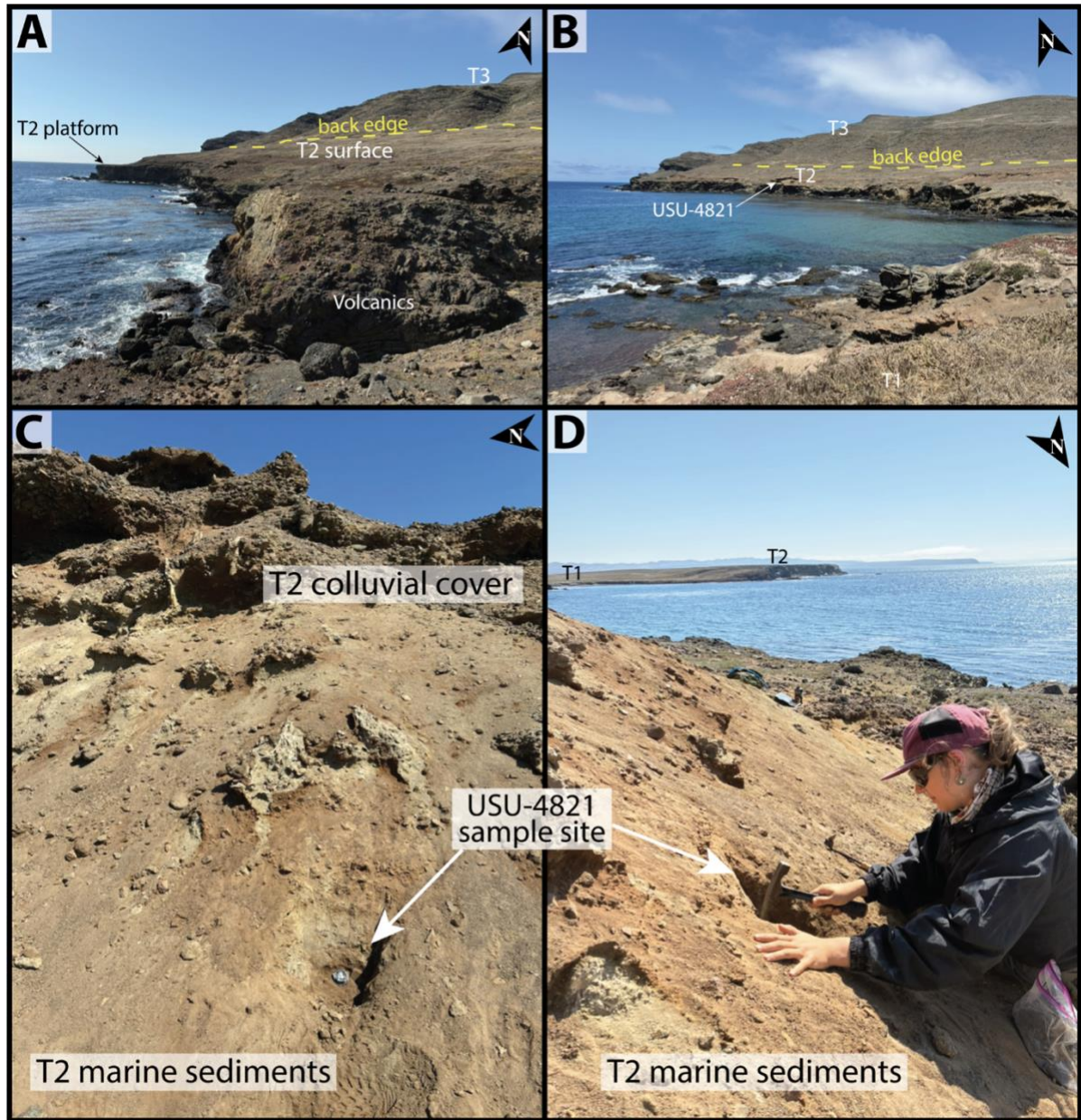


Figure 12. Photos of the T1 and T2 marine terraces near Forney Cove. (A) and (B) show two perspectives of the uplifted T2 terrace. (C) and (D) show the IRSL sample (USU-4821) site, located 14 m above modern sea level at 34.064442, -119.918467.

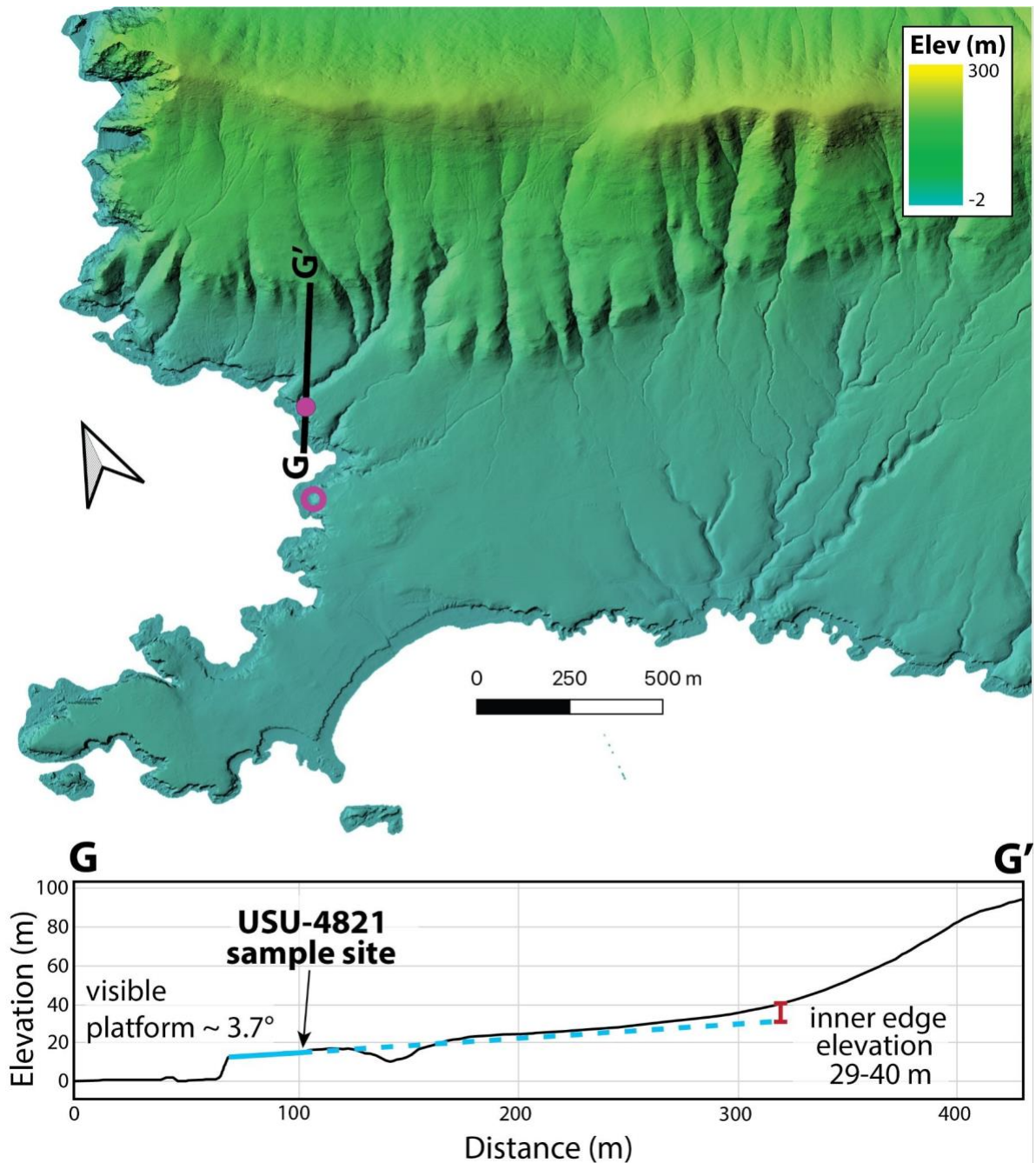


Figure 13. Shows hillshade overlain with 1-m resolution DEM (top) of Forney Cove area (location shown in Fig. 2). Below, a topographic profile along G–G' that crosses our sample site. The inner edge elevation is estimated to be 29–40 m at this location, which is based on the minimum slope value of 3.7° derived from the slope of the modern platform (blue line), and a maximum elevation estimated by the increase in roughness and gradient that occurs on the surface at 40 m elevation, where the surface deposits meet the paleo sea cliff.

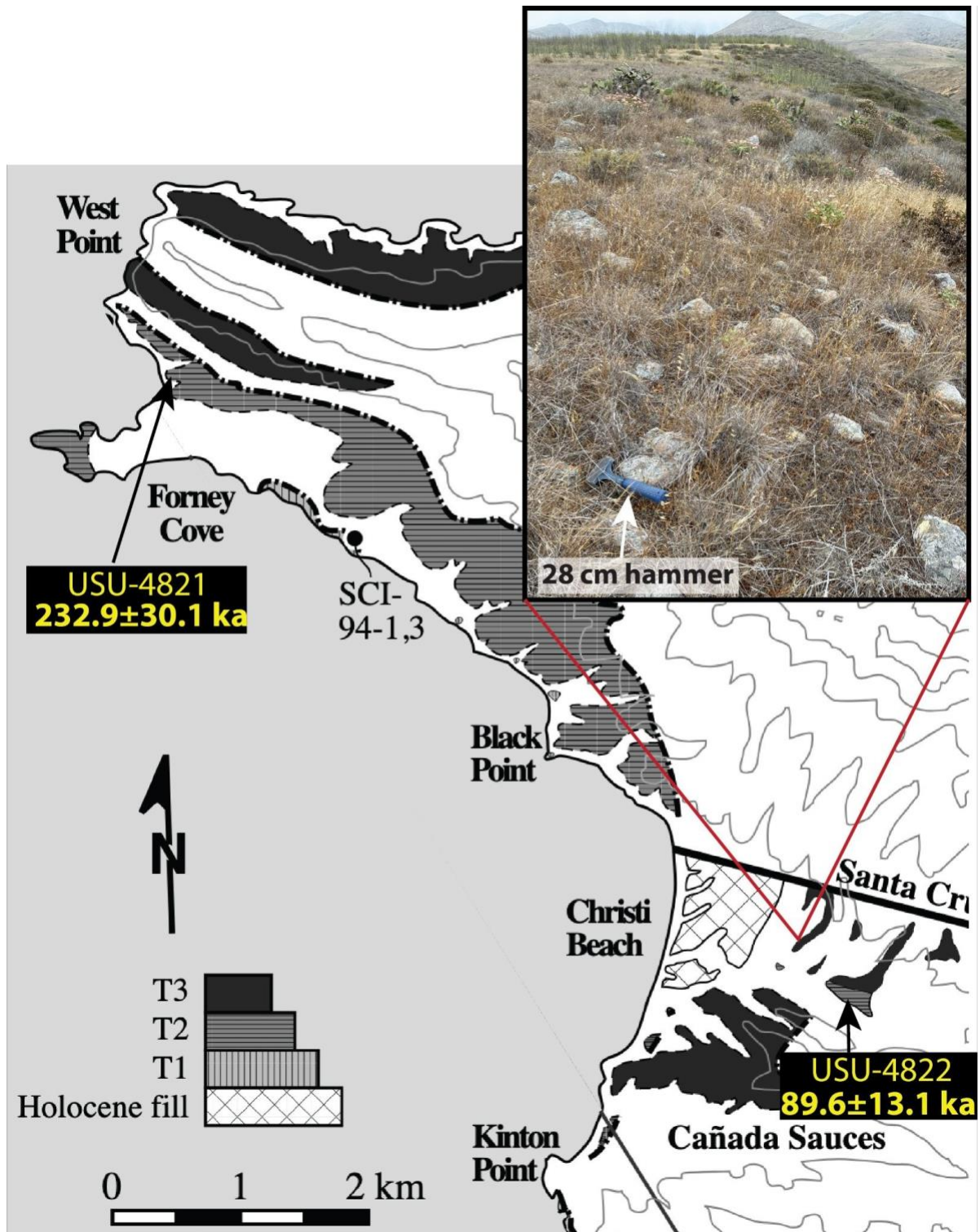


Figure 14. Modified map from Pinter et al. (1998a), showing their elevation correlations of the T2 and T3 marine terraces with what they refer to as T2 and T3 age fluvial deposits in the Christi valley. Their U-series age shown as black dot with an SCI-#, our IRSL sites are indicated with black arrows and a USU-#. Field photo in top right was taken in July, 2025, on top of what previous authors map as a T3-age fluvial terrace south of the fault. The photo

shows lichen-covered homogeneous volcanic boulders that derive from the volcanic bedrock north of the fault. The elevations of T3 terrace correlate with the elevations of these deposits, however, we map these deposits as alluvial fans, rather than fluvial deposits (mapping shown in Fig. 3c).

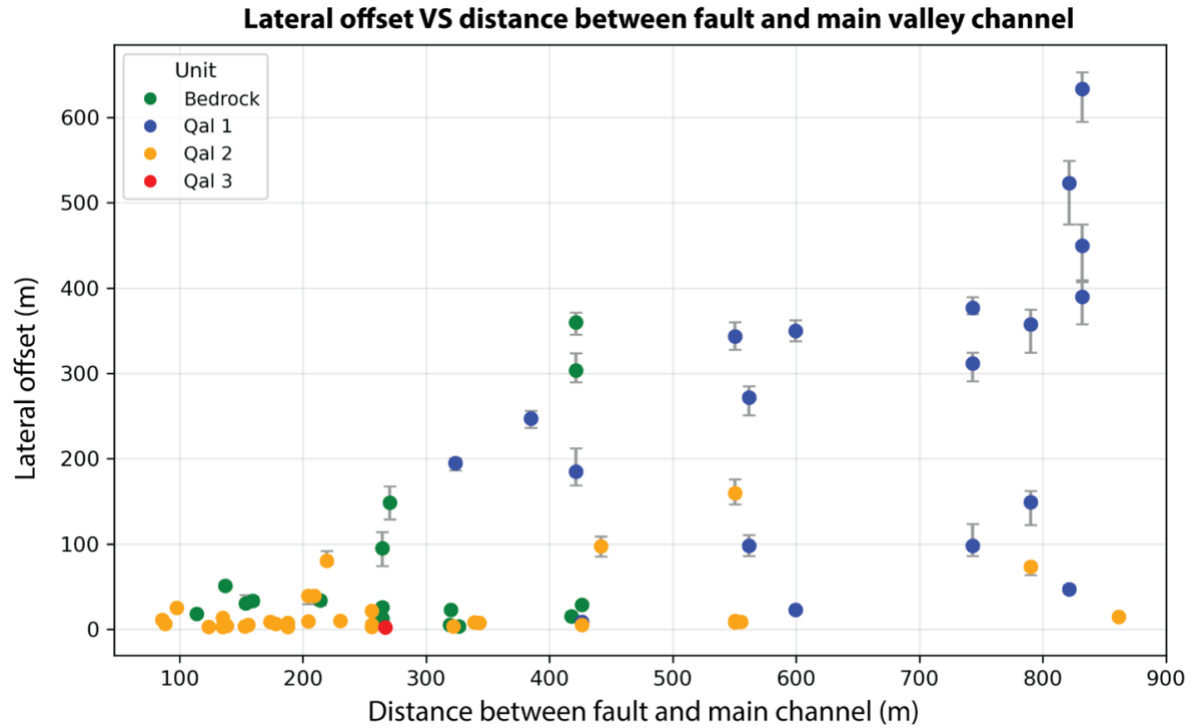


Figure 15. Plot showing lateral offset VS distance to the main channel. Dots colored to show unit ages that correlate to offset channels that have incised into them, providing age proxy. Younger units tend to show less offset and generally cluster at locations where the main channel is closer to the fault, while older units tend to show more offset, and cluster at locations where the main channel is ~400 m or more from the fault.

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