2025 SCEC Report: Cracking the Klamaths: A not-so-rigid block linking the Walker Lane to the Mendocino Triple Junction

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Introduction: The dynamics of the Mendocino Triple Junction (MTJ) region involves a broad area affected by the interplay of plate-boundary forces and gravitational potential energy of the continental interior (Humphreys and Coblentz, 2007). South of the MTJ, the transform margin entrains nearly the entire state of California, driving northwestward motion of the rigid Great Valley-Sierra Nevada block and strike-slip motion across the Walker Lane (Unruh et al., 2003; Hammond and Thatcher, 2005). North of the MTJ, oblique convergence and slab rollback in southern Cascadia entrains the Oregon Coast Block, which rotates clockwise in the hangingwall of the subduction interface and accommodates northward motion of the Great Valley-Sierra Nevada block and extension of the Basin and Range Province (McCaffrey et al., 2013; Humphreys and Coblentz, 2007). Some of the ~7 mm/yr transform motion across the northern Walker Lane (Hammond et al., 2011) continues northward into eastern Oregon (e.g. Waldien et al., 2019), but more than half appears to be accommodated in a complex and distributed manner between the Great Valley and Oregon Coast Range, across Klamath mountains terrane of northwesternmost California (Unruh and Humphrey, 2017; Angster et al., 2021). Suggested mechanisms of this deformation include west-northwest directed dextral shear (Unruh and Humphrey., 2017) or transpression (Angster et al., 2021). East-west extension may also be present due to slab rollback (Humphreys and Coblentz, 2007) or underplating and gravitational instability of thickened forearc crust (Delph et al., 2021; Platt, 1986). Because this deformation may be directly related to the plate boundary transition at the MTJ, where slab-pull from subduction gives way to transform motion, quantifying the style and rate of deformation in northern California provides key information for developing geodynamic models to constrain absolute stress on faults (e.g. Humphreys and Coblentz, 2007). Due to the strong imprint of the locked subduction interface on the geodetic strain field (McCaffrey et al., 2013), sorting out the style and rate of permanent deformation here requires geologic investigations of active faulting.

Despite the presence of several mm/yr of deformation across the Klamath mountains terrane (Hammond and Thatcher, 2005), prior to this work no confirmed active faults were known from the Klamath mountains. Thus the Klamath mountains terrane has been treated as a separate rigid block (e.g., McKenzie et al., 2022; Furlong et al., 2024), or as part of the Oregon Coast block (McCaffrey et al., 2013; Unruh and Humphrey, 2017). Based on the presence of extensive underplated schistose rocks (Chapman et al., 2024), we hypothesized that the Klamath terrane is not a rigid block but rather it should be transected by active faults that deform the terrane in response to complex boundary conditions on its margins (and possibly its base). These active faults may have been overlooked until now because the region is elevated, eroding, and densely forested, obscuring evidence for faulting. We confirmed this hypothesis by documenting four previously overlooked active faults, the longest of which accommodates east-west extension across the high terrain of the eastern Klamath mountains.

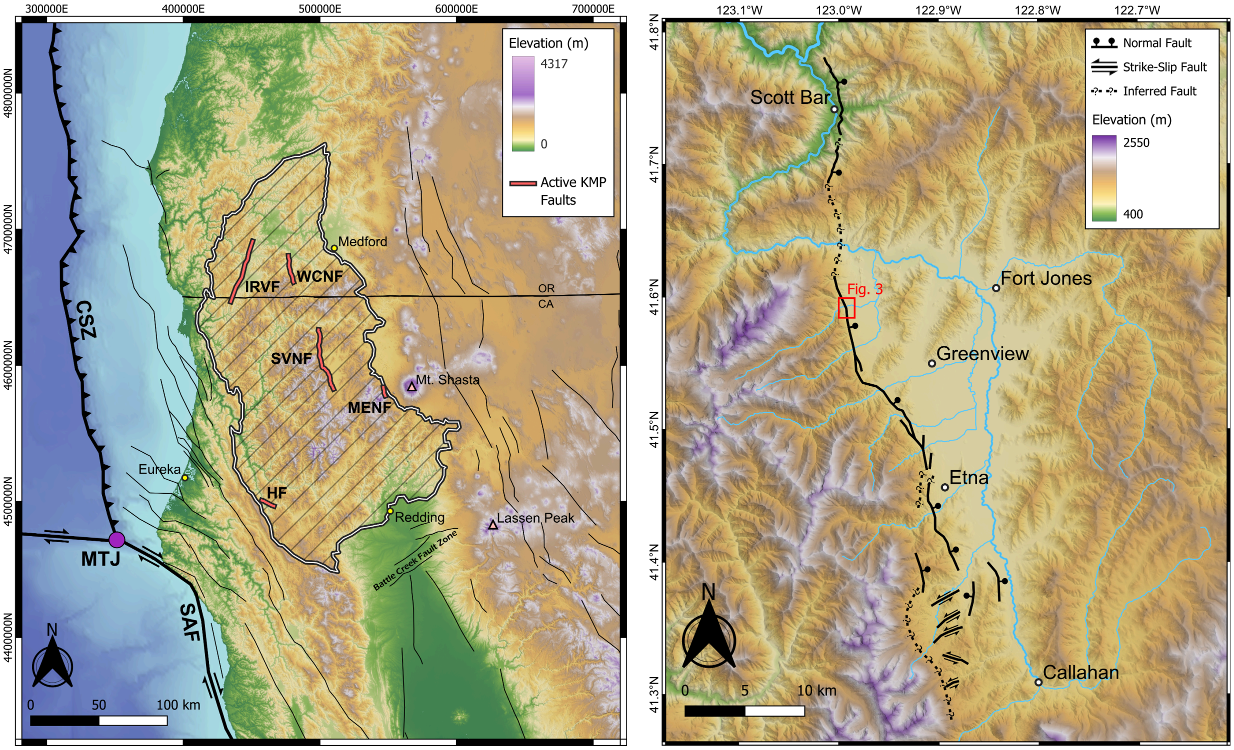

Figure 1. Left: Active faults in and around the Klamath Mountains province (KMP) overlain on modern hillshaded topography. KMP outlined in black with hashed interior. Thin black lines denote active faults from the 2023 USGS National Seismic Hazard Model. Thick black lines denote plate boundaries: SAF: San Andreas Fault; CSZ: Cascadia Subduction Zone. Red lines denote newly identified active faults in the KMP: WCNF: Williams Creek normal fault; IRVF: Illinois River Valley fault (Yule, 1996; Kirby, 2023); SVNF: Scott Valley normal fault; MENF: Mount Eddy normal fault; HF: Hyampom fault. Right: Topography of Scott Valley and confirmed and inferred traces of the Scoff Valley normal fault. Box labelled Figure 3 shows location of Shackleford Creek slip-rate site.

Results: UC Davis MS student Ryan Lynch used recently released USGS 3DEP lidar datasets to search for and map active faults within the Klamath Mountains terrane of northern California (Fig. 1). From this work, he discovered a significant active north-south striking, east-dipping normal fault bounding Scott Valley, located within a basin surrounded by the highest topography of the Klamath mountains. The main strand of the Scott Valley normal fault (SVNF) extends for 47 km in a north-south direction, and the total fault length may be as much as 63 km. His search also located two additional active north-striking normal faults in the eastern part of the Klamath range, and one active dextral fault in the southwest part of the range.

Lynch's detailed field study focussed on mapping the SVNF and documenting sites suitable for quantifying its rate of slip (Fig. 1). The geomorphic expression of the SVNF is most pronounced between the town of Etna and Shackleford Creek. Along this extent lies the best-preserved fault scarps and clearest evidence for recent fault activity. Field measurements taken from a slickensided granodioritic fault outcrop here show that the SVNF is purely dip-slip

with a dip of 60°, typical for a normal fault. Geomorphic evidence for fault activity ceases for an 8 km-long stretch north of Shackleford Creek where the Scott River exits the valley. Lynch interprets that geomorphic evidence for fault activity has been covered by a series of large landslides and removed by fluvial action of the Scott River. North of this stretch, the fault scarp reappears and continues for 9 km over rugged terrain while displaying an eastward dip as it crosses ridges and gullies. The Shackleford Creek site (Fig. 2) was chosen for geochronology (Fig. 3) because of the clear fault scarp and access to suitable deposits. We applied multigrain infrared stimulated luminescence (IRSL) dating to the faulted sedimentary deposits at this site to quantify their age and deduce the slip rate of the Scott Valley normal fault.
sample collected from road cut exposure at base of the terrace. Sample collection depths marked and labeled adjacent to their corresponding kernel density estimate plots of measured equivalent dose (De) populations. The kernel density estimate plots include a boxplot depicting median as a thick central line, first and third quartile as box limits, whiskers denoting ± 1.5 interquartile ranges, and dots further outliers. The vertical blue line in the kernel density estimate plots represents the Central Age Model D_e estimate; the vertical red line represents the Minimum Age Model D_e estimate.

Slip rate of the SVNF at the Shackleford Creek site is a minimum estimate because T6 deposits have been covered by younger T5 deposits on the fault hangingwall. As excavation of T5 did not encounter the surface of T6 to a depth of 2 meters, it may be interpreted that the SVNF has vertically displaced T6 by at least 2 meters more than estimated. Combining the estimated minimum dip-slip displacement of the T6 surface ($14.5^{+1.9}_{-1.5}$ meters) with the IRSL-derived age of T6 of 21.2 ± 4.4 ka yields an estimated minimum mean slip rate of 0.7 ± 0.2 mm/yr for the SVNF at Shackleford Creek. Note that all slip, age and rates are stated with 95% confidence.

Based on its length and the seismogenic thickness here, it is estimated that the SVNF is capable of producing a M_W 7.0 to 7.2 earthquake. This moment magnitude (Mw) is based on the scaling relationships of Thingbaijam et al. (2017) with fault rupture area as the predictor. The estimated earthquake magnitude is somewhat elevated compared to similar length normal faults of the Basin and Range province due to the unusual depth of the brittle-ductile transition, which is estimated to be at a depth of 25 km in this region (Zeng et al., 2022). The relatively deep seismogenic thickness beneath Klamath mountains is attributed to lower temperatures in the crust and upper mantle due subduction of the Gorda plate, which results in a more brittle structural setting and allows for deep crustal seismic activity (Zeng et al., 2022). For this analysis a planar 60° dipping fault is assumed. If instead the SVNF is listric, similar to the model proposed by Platt (1986) for forearc normal faulting, the seismogenic depth may be shallower while rupture area would likely increase.

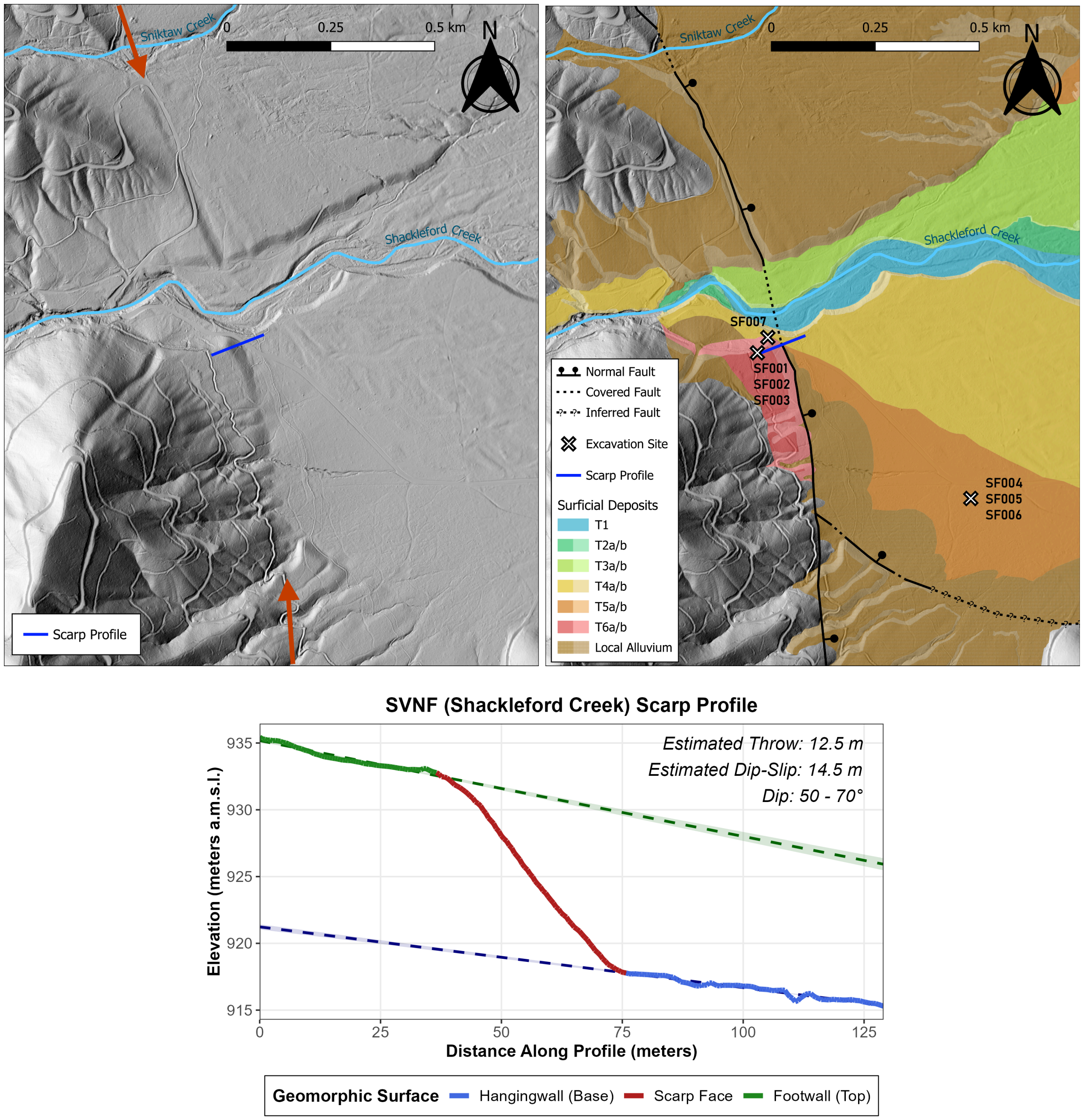

Figure 2. Hillshaded lidar topographic map (top, left) highlights scarp of the Scott Valley normal fault adjacent to Shackleford Creek. Surficial geologic map (top, right) shows deposits sourced from Shackleford Creek categorized by depositional age from youngest to oldest from T1 to T6. Units labeled “a” denote relict depositional surfaces while units labeled “b” denote eroded terrace edges. Deposits not sourced from Shackleford Creek noted as Local Alluvium. Locations of IRSL geochronology sampling sites marked and labeled. Plot shows a terrain profile across the scarp of the Scott Valley normal fault at Shackleford Creek (location shown on hillshade map, above). This scarp preserves an estimated 12.5 meters of throw and 14.5 meters of dip-slip displacement.

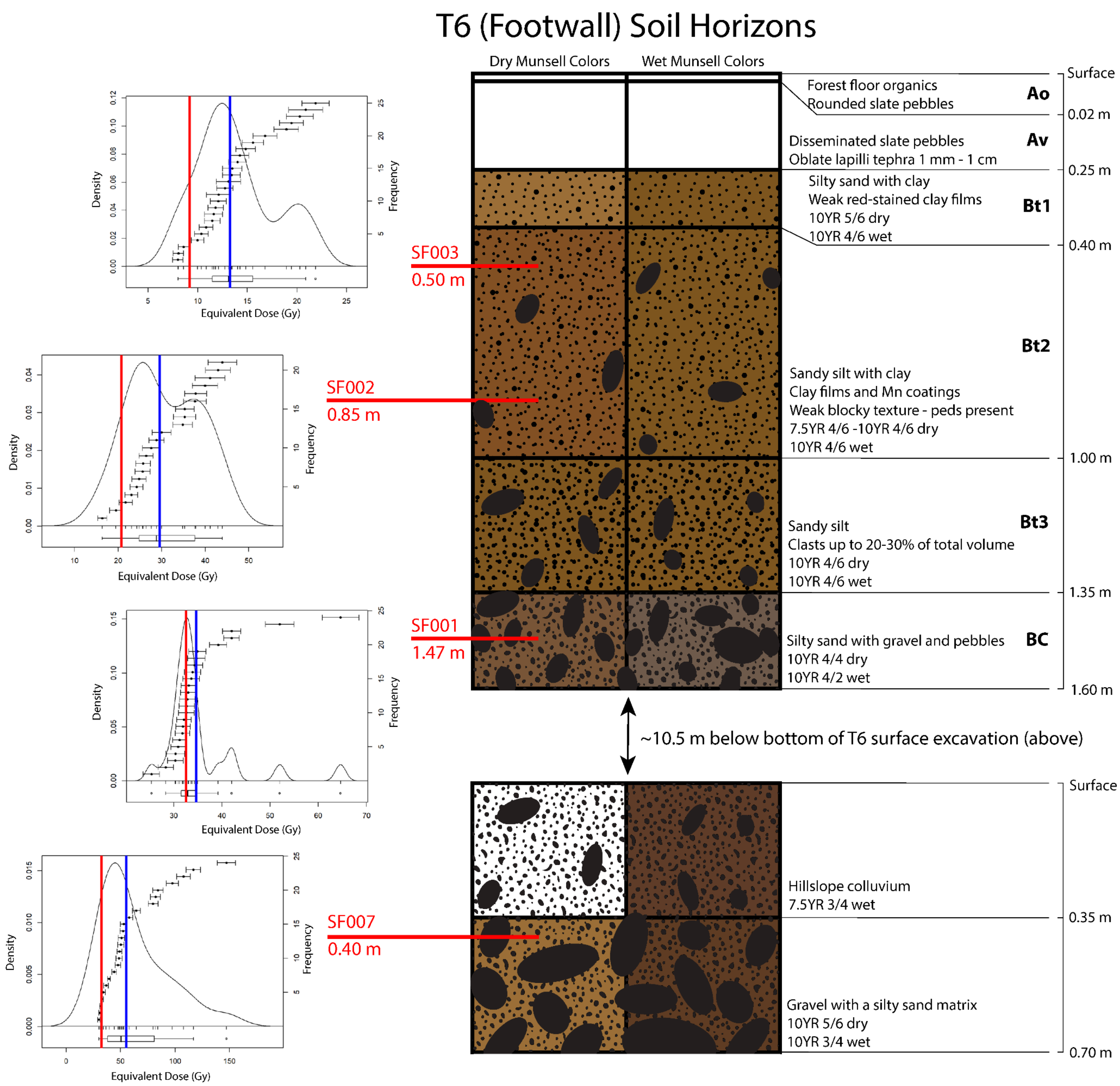

Figure 3. IRSL age results and soil characteristics of T6 terrace at Shackleford Creek. Soil horizons marked and labeled. Note ~10.5 meter stratigraphic break separating lowest T6

Broader Impacts: This project quantifies earthquake hazard in a region of California where no active faults were previously mapped. Though remote and sparsely populated, the Klamath Mountains region hosts critical water infrastructure including Shasta Dam, a keystone of the State Water Project that impounds the largest reservoir in California. The study area resides at the boundary between SCEC's focus on California and the San Andreas fault system and CRESCENT's focus on the Cascadia subduction zone, providing a bridge between these two earthquake centers. This project supports a UC Davis MS student thesis by Ryan Lynch and involves a collaborator new to SCEC, Dr. Kathleen Rodrigues, from the Desert Research Institute (DRI).

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