Paleoseismic investigation of the Mohawk Valley fault zone, Sierra County, northeastern California

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ABSTRACT

Paleoseismic studies and surficial geologic mapping indicate that the Mohawk Valley fault zone (MVFZ), the westernmost in the transtensional northern Walker Lane, has been the source of multiple latest Quaternary earthquakes. This study presents evidence for repeated latest Quaternary strike-slip earthquakes along the eastern of two strands forming the southern MVFZ. Trench relationships and radiocarbon dates constraint a sequence of three latest Quaternary paleoearthquakes, with the most recent occurring at or after 2,100 years ago. A buried, laterally offset channel provides a minimum right-lateral slip rate of 0.4 ± 0.1 mm/yr on the eastern strand. However, the rate was determined near the southern terminus of the eastern strand and characterizes only a portion of the motion across the widely-distributed MVFZ.

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1. INTRODUCTION

The Mohawk Valley fault zone (MVFZ) defines the western margin of the Sierra Nevada - Basin and Range transition at approximately 39.30^{o} N to 40° N latitude in NE California. The zone extends over 75 km from south of Sierra Valley northwest to its intersection with the Sierra Nevada-Cascade Range boundary zone (Sawyer, 2009) near Quincy in American Valley (Figure 1). The fault zone is expressed as a prominent topographic trough, regional lithologic and structural boundaries, and seismicity lineament. This study is motivated by several factors including: a) previous geologic observations that suggest the MVFZ is potentially an active strike slip fault; b) frequent seismicity, including earthquake swarms, that are strongly suggestive of an active fault; and 3) geodetic measurements and models that predict the fault zone accommodates approximately 3 mm/year of right-lateral shear (Figure 1). Herein, we present surficial mapping, paleoseismic trenching observations and radiocarbon age constraints to demonstrate Holocene strike-slip surface ruptures on the eastern strand of the southern MVFZ.

This study was largely funded by Award 04HQGR0089 from the U.S. Geological Survey National Earthquake Hazards Program (NEHRP). The study was made possible by Mr. Lewis Van Vleck, who granted us permission to excavate numerous exploratory trenches and test pits on his property in Sierra Valley and who provided his track-hoe excavator, often with little or no advance notice. We thank the Ramellis of Sierra Valley for their role as our initial liaison to Mr. Van Vleck. We have benefited from the technical peer review of Steve Wesnousky and Craig dePolo.

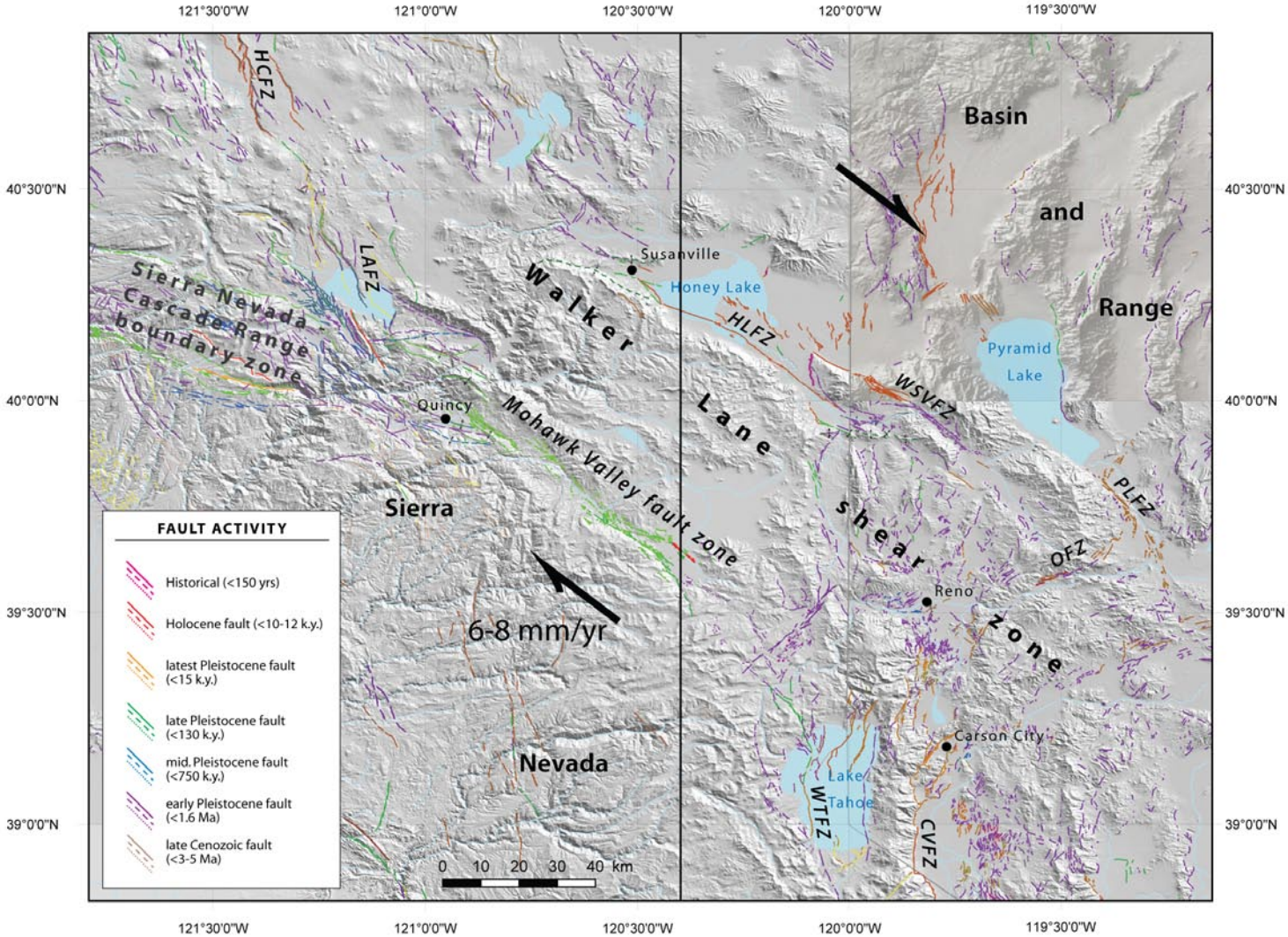

Figure 1. Regional tectonic setting map. Map shows principal Quaternary structures of the northern Walker Lane shear zone and adjacent seismotectonic provinces. Arrows represent right shear geodetically determined across the northern Walker Lane shear zone. In addition to our mapping of the fault zone, other sources are shown including unpublished mapping by Mark Hemphill-Haley (1991), the National Quaternary fault and fold map of the U.S. Geological Survey (online resource), and Sawyer (2010). Fault abbreviations as follows: CRFZ—Carson Range fault zone, HCFZ—Hat Creek fault zone, HLFZ—Honey Lake fault zone; LAFZ—Lake Almanor fault zone, OFZ—Olinghouse fault zone, PLFZ—Pyramid Lake fault zone, WSVFZ—Warm Springs Valley fault zone, WTFZ—West Tahoe fault.

2. Reconnaissance mapping of the Mohawk Valley fault zone

Published maps of the Mohawk Valley fault zone (e.g. Saucedo and Wagner, 1992; Jennings et al., 1994; Grose, 2000) show an anastomosing network of northwest-striking bedrock faults concealed by Quaternary alluvium and separating primarily Precambrian rocks and Cretaceous-Jurassic plutons on the west from Miocene-Pliocene volcanic rocks on the east. Scarps on the Mohawk Valley floor west of Clio were recognized by Alt et al. (1990) as geomorphic evidence for young faulting. To date, no maps depicting young fault-related features along the MVFZ have been published.

We generated a neotectonic strip map of suspected fault-related features to portray potential active strands of the MVFZ (Figure 2). The map was generated from stereoscopic analysis of vertical airphotos at 1:40,000 scale from 1989, and from limited aerial and field reconnaissance. The map shows suspected fault-related scarps, transpressional structures, and lineaments along the fault zone.

In general, we found the fault zone to be highly distributed, poorly integrated and to consist of overlapping linear to anastamosing curvilinear fault traces and suspected fault traces (Figure 2). We recognize three principal structural elements or distinct fault strands within the fault zone, which we call the eastern, western, and northern strands. The southern 37 to 44 km of the MVFZ comprises the subparallel eastern and western strands. These strands are separated by 4 to 5 kilometers in Sierra Valley, converge to 2 to 3 km in southern Mohawk Valley, and appear to merge in Long Valley near Sloat. Here the fault zone appears to step 3 to 5 km west and to continue to eastern American Valley as the northern strand (Figure 2). Here the MVFZ intersects the W-NW-striking Sierra Nevada-Cascade Range boundary zone (Figure 1) and exhibits evidence of possible transpressional deformation, including a sizeable closed depression in western Thompson Valley and inferred northward deflection of Mill Creek in American Valley (Figure 2).

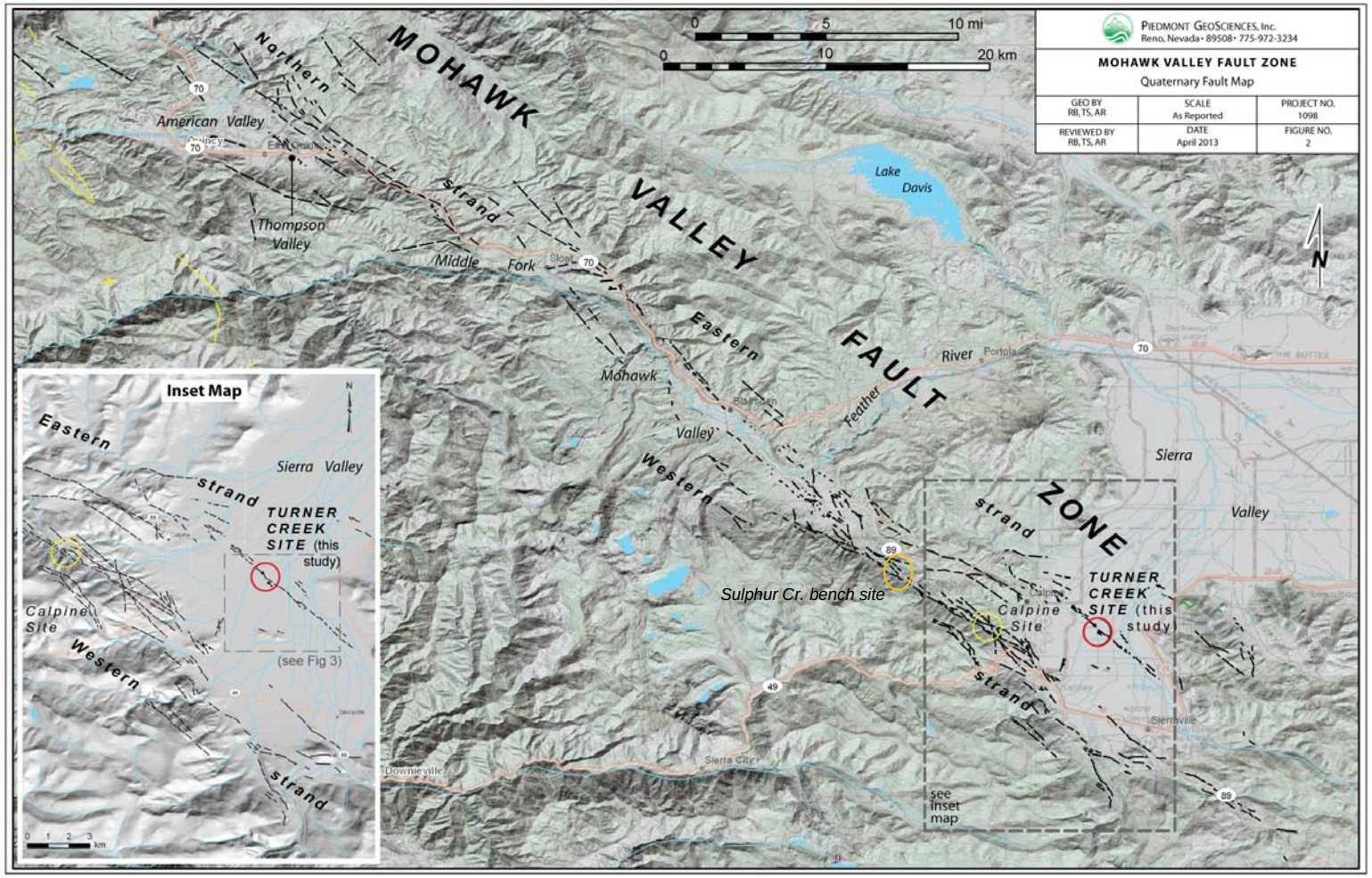

Figure 2. **Mohawk Valley fault zone.** Photogeologic strip map of the Mohawk Valley fault zone showing confirmed and suspected fault-related features within the zone, as well as, locations of paleoseismic sites.

The western strand bounds the steep eastern front of the northern Sierra Nevada in southwestern Sierra Valley and in Mohawk Valley (Figure 2). The compound escarpment reflects late Quaternary movement along multiple traces of this distributed fault zone. Reconnaissance level mapping suggests that the strand continues discontinuously to the southeast and may extend as far as the Independence Lake area (Olig et al., 2005; Figure 1). We map the western strand as a continuous series of overlapping fault traces from southern Sierra Valley as far northwest as about the latitude of Blairsden (Figure 2). Our mapping suggests that the strand is discontinuous along the west side of Mohawk Valley. However, recent LiDAR- and field-based mapping studies (Gold et al., 2013a; Redwine and Adams, 2010) reveal greater continuity to the fault in this area. We expect continuity of the fault zone will be established as higher resolution remotely-sensed data becomes available, particularly in heavily forested terrain.

The linear eastern strand crosses the flat alluvial floor of Sierra Valley as a series of low scarps, low 'hanging' and abandoned drainage swales, closed depressions, and aligned linear reaches of deflected drainage channels and tonal lineaments (Figure 3). Surface drainage is impeded in several places along the downthrown southwest side of the fault. In addition, the fault is delineated by abrupt vegetation changes that seemingly signify the presence of a shallow groundwater barrier; this interpretation is consistent with anecdotal water-well information provided by landowner Mr. L. Van Vleck. As discussed below, we document stratigraphic evidence of apparent reverse faulting within a left stepover between two overlapping traces of the eastern strand (Figure 4) consistent with right-lateral strike-slip faulting. The Mounds in southern Sierra Valley are transversely (i.e., east-west) oriented volcanic hills on the valley floor that also appear to reflect transpressional deformation, perhaps associated with a restraining left stepover from the southern end of the eastern strand to the through going western strand (inset, Figure 2). The eastern strand traverses the volcanic uplands between Sierra and Mohawk valleys and continues bordering eastern Mohawk Valley, paralleling and crossing the Highway 70 alignment, to northwest of Sloat. The map geometry of the eastern and northern strands forms

a 3 to 5 km wide left stepover in the overall MVFZ (Figure 2).

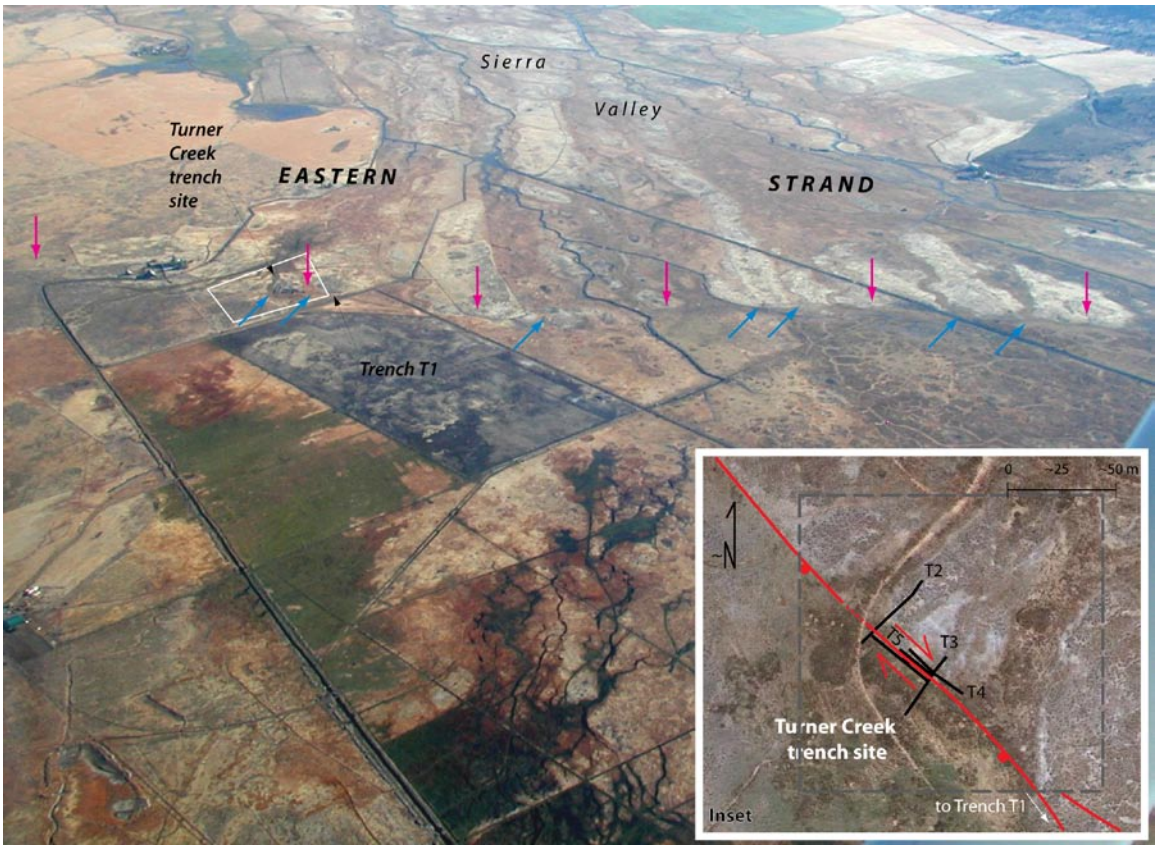

Figure 3. Oblique aerial photographs of the eastern strand, MVFZ. Low-oblique aerial photograph looking to the northeast at expression of eastern strand (red arrows) on floor of southwestern Sierra Valley. Note tonal contrast and numerous abandoned drainage swales (blue arrows) beheaded along the fault. Inset is high-oblique aerial photograph showing approximate locations of trenches excavated during this study.

North of the Middle Fork Feather River, the northern strand is distinct through easternmost Thompson and American valleys (Figure 2). A sizeable closed depression in Thompson Valley, at the intersection of Highway 70 and the Quincy-LaPorte Road (Figure 2), appears to reflect transpressional deformation along the northern strand. In American Valley the inferred transpressional structure impedes eastward-flowing drainages and appears to have deflected Mill Creek about 3 km northwest from formerly draining into Taylor Creek to now draining into Spanish Creek. The abandoned paleochannel of Mill Creek forms a broad alluvial windgap through the bedrock hills delineating the structure that is flanked on the south by a (uplifted?) broad stream terrace opposite the mouth of

Chendler Creek (Figure 2). North of the intersection with the dextral Sierra Nevada-Cascade Range boundary zone, the northern strand becomes geomorphically indistinct and its expression is lost in the deep canyon of Spanish Creek along the west flank of Mt. Hough (Figure 2).

3. PALEOSEISMIC INVESTIGATION OF THE EASTERN STRAND

Turner Creek Site

The linear eastern strand of the Mohawk Valley fault zone extends northwest across southern Sierra Valley and through eastern Mohawk Valley (Figure 2), and has a geomorphic character consistent with strike-slip deformation. The fault is expressed on the floor of Sierra Valley by aligned linear drainages and vegetation lineaments, low southwest-facing scarps, uplifted alluvial surfaces and beheaded drainage swales, and topographically closed depressions (Figures 3 and 4). In particular, the fault is delineated by a continuous linear trace that laterally deflects several drainages, including near our trench site.

We excavated ten trenches normal to, and six trenches parallel to, the intrabasin eastern trace at Turner Creek, approximately 6 km northwest of Sierraville and 5 km southeast of Calpine (Figures 2 and 3). The trenches exposed a layered sequence of faulted and unfaulted latest Quaternary alluvial deposits suitable for constraining recent fault activity. Graphical logs of a subset of trench exposures are presented in Plates 1a and 1b along with descriptions of the exposed trench units. We omit description of trenches that were used to explore for laterally offset features or to establish continuity of depositional units.

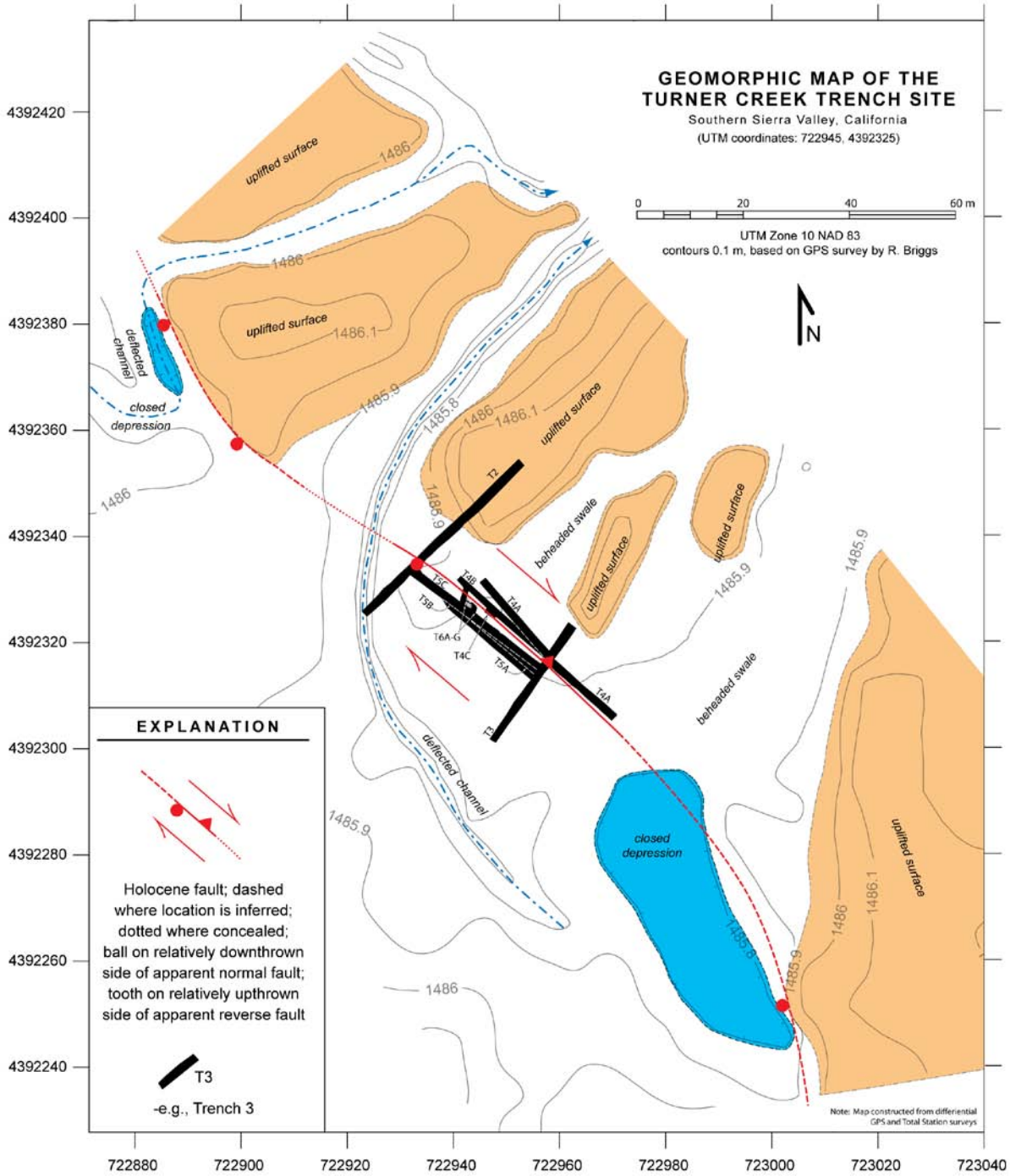

Figure 4. Turner Creek site map. Topographic map of the Turner Creek trench site, based on GPS and total-station surveys, showing the mapped trace of the fault through the site, uplifted alluvial surfaces with beheaded drainage swales, and the location of two closed depressions and several exploratory trenches. Note that closed depressions are adjacent to the more northerly striking sections of the fault and apparent reverse slip observed along northwest striking section, consistent with northwest directed right slip.

The linear fault trace forms a series of low (generally <1 m) southwest-facing scarps that deflects low-gradient drainages, and apparently forms a groundwater barrier based on the abrupt vegetation change that occurs across the fault trace (Figure 3). The uplifted hanging wall has been dissected by numerous shallow drainage swales, several of which have been beheaded by recent surface faulting. At the Turner Creek site the fault is expressed by to a low southwest-facing fault scarp with two shallow closed depressions along its base, including one that deflects and occupies a short reach of the Turner Creek channel (Figures 3 and 4).

The trenches exposed a widespread sequence of flat-lying alluvial deposits with channel infillings, a tephra layer, several diatom-rich layers, buried soils, fragments of detrital wood and charcoal, localized warping and tilting of strata, and several high-angle faults and fractures. The recently active faults are the western-most faults exposed in the cross-strike trenches T2 and T3, and they tend to bound fissures containing multiple packages of chaotic fissure fill (Plate 1a). A number of older faults were truncated by a period of erosion represented by an unconformity in the lower exposed section.

The primary fault strand is marked at the site by a 20-30 cm high, southwest-facing scarp that beheads a broad, low gradient drainage swale (Figure 4). Trench T1 was about 12 m long and 2 m deep, and was excavated across a low scarp as part of the proposal effort for this study (Figures 3 and 5). The trench exposed a well-defined fault striking N49^{o}W and dipping 62°NE near the bottom of the trench. The fault widens or 'flowers' updip and extends to within about 50 cm of the ground surface (Figure 5). Slickenside stria plunging 10.5^{o} to the northwest suggest that movement on the fault is predominantly right-lateral strike-slip with a subordinate reverse component. The reverse-drag manner in which alluvial units on the northeast, or relatively uplifted, side of the fault have been gently folded also is consistent with a subordinate reverse component. In addition, the stratigraphic offsets across the fault are characterized by apparent reverse motion, possibly

related to a left stepover between this fault trace and an overlapping , sub-parallel trace to the east.

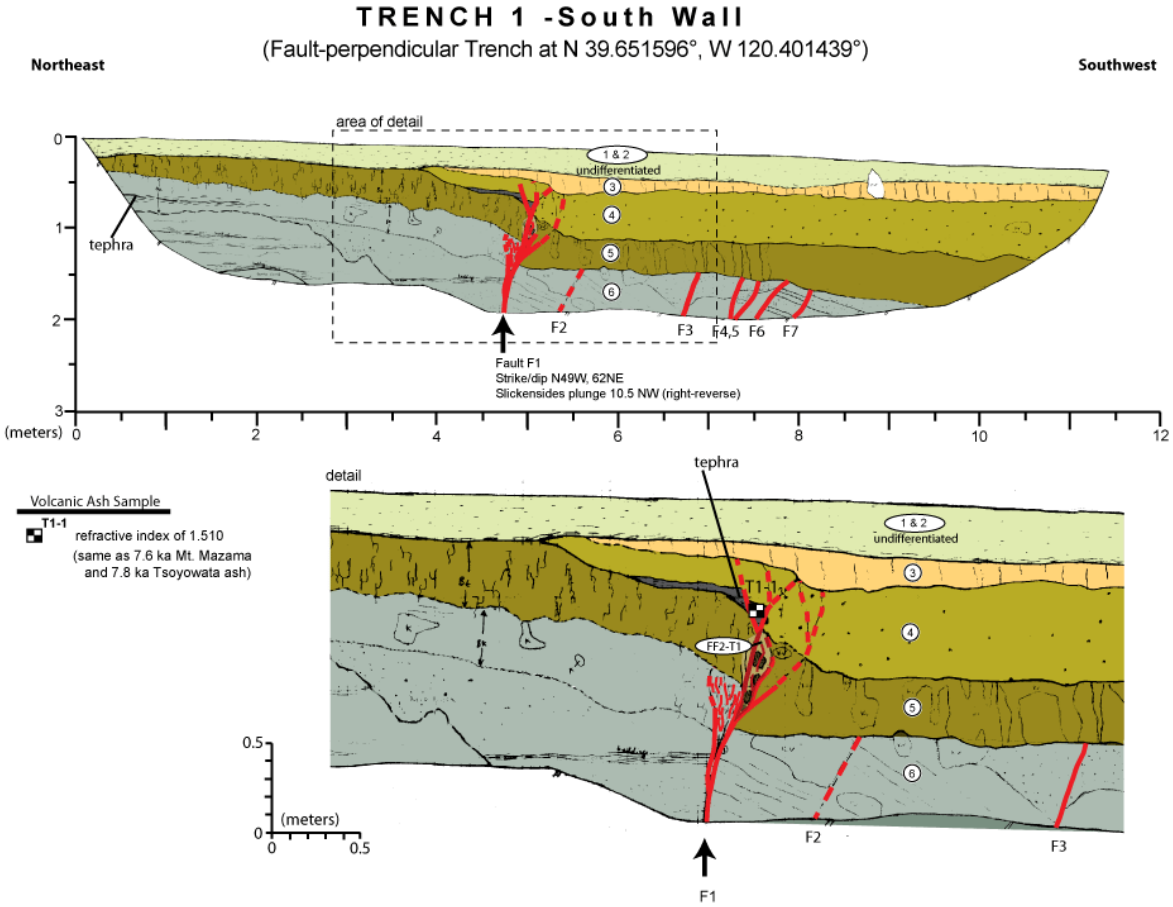

Figure 5. Log of Trench T1. Graphical log of south wall of trench T1 showing packages of Quaternary alluvium and the position of a tephra samples tentatively correlated to the Mount Mazama or Tsoyowata ash in relationship to various faults and fractures. Note modest apparent reverse-drag folding of trench strata on northeast side of fault and sub-horizontal orientation of slickensides on fault plane. For a description of trench units, see Plate 1b.

Trench T2 (Plate 1a) crossed the continuation of the same scarp crossed by trench T1 a few hundred meters to the northwest (Figure 3). Trench exposures revealed as a zone nearly 5 m wide of high-angle faults and fractures. The most recent movement has occurred within the western 1 m of the zone, primarily along a fault that strikes N46^{o}W, dips 76°SW and extends to within about 40 cm of the

ground surface. Deformation associated with the fault juxtaposes trench unit 6 against units 5 and 4 in an apparent reverse relationship and gently warps units 5 through 2 in an apparent reverse-drag manner, similar to the style of deformation uncovered in trench 1 (discussed above). However, higher in the exposed section the fault dips steeply to the northeast and exhibits apparent normal offset of overlying units 3 and 2 across an extensional fissure (Plate 1a). The apparent change in the style of vertical deformation upsection along the same fault is indicative of strike-slip faulting. Coupled with the abrupt thickening of alluvial units across the fault, these observations establish the primary component of lateral slip on the eastern strand of the southern Mohawk Valley fault zone. Only uppermost alluvial unit 1 extends unbroken across the fault (Plate 1a).

Fault-normal trench T3 crossed the same scarp and exposed a fault striking N40^{o}W, dipping 82°SW and, exhibiting apparent normal offset of the exposed stratigraphic section across a near-vertical fissure (Figure 6; Plate 1a). As in trench 2, all units with the exception of unit 1 have been downwarped into the fault. Stratigraphic relations suggest 65 to 75 cm of cumulative down-to-the-southwest apparent vertical motion across the fault (Figure 6). The fault-bounded fissure contains three discrete packages of generally chaotic fill materials. The youngest fissure-fill deposit, unit FF1, contained charcoal fragments radiocarbon dated at 2,150 to 1,960 Cal yr BP (Table 1). The fault zone was buried by three unfaulted units: scarp-derived colluvium C1, fissure fill FF1, and overlying alluvial unit 1.

Paleoearthquake history

Trench exposures at the Turner Creek site provide a record of three discrete paleoearthquakes, as well as, an earlier period of faulting and tilting along the fault and a separate liquefaction event all during the late Quaternary. The sequence of three events is recorded by discrete stratigraphic offsets, fissure-fill deposits, scarp-derived colluvium, warped strata, and consistent upward terminations of faults and fractures. Earlier fault activity is suggested by stratigraphic offsets and apparent tilting in the lower exposed stratigraphic section. An intermediate sequence locally exhibits evidence of liquefaction.

The oldest discrete earthquake we identify, paleoearthquake PE3, is represented by down-to-the-southwest offset of unit 6 and subsequent deposition of alluvial unit 5 largely against the base of the associated fault scarp. In addition, the event is recorded by emplacement of fissure-fill deposit FF3 (Figure 6; Plate 1a). Detrital charcoal from unit 6 yielded AMS radiocarbon dates of 40,200 ±520 ^{14}C yr to >48,000 ^{14}C yr (Table 1). Detrital charcoal from the base of unit 5 yielded an AMS radiocarbon date of 12,700 to 12,250 Cal yr BP (Table 1). Upper unit 5 contains a distinct channel-fill sequence, designated "Channel A" (see below), that contains volcanic ash having a refractive index (1.510) that precisely matches that of the Mt. Mazama or Tsoyowata tephras (Kittleman, 1973), which has been dated at 7,627 ±150 Cal yr BP (Zdanowicz et al., 1999).

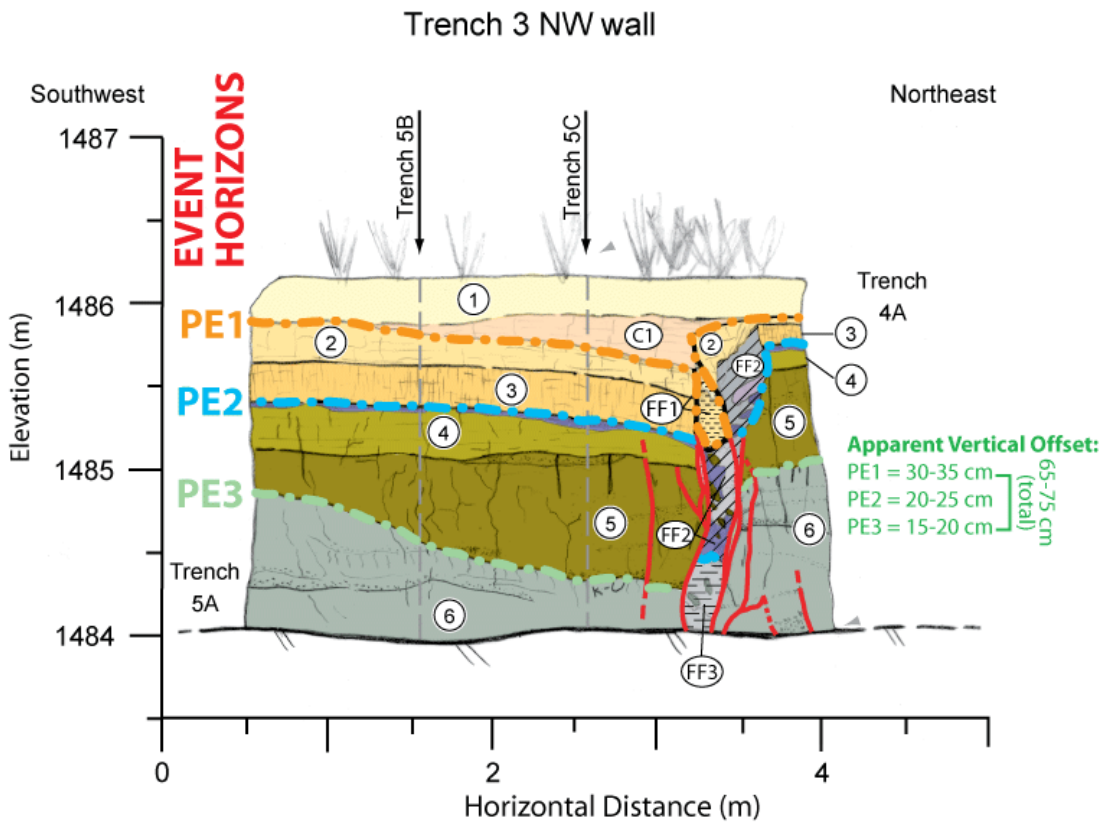

Figure 6. Log of a portion of Trench 3. Graphical log of a portion of the northwest wall of trench 3 showing the fault zone in relation to various alluvial units, and fissure filling (e.g., FF2) and scarp-derived colluvial (i.e., unit C1) deposits; for an explanation of the log and/or for description of trench units, see Plate 1b. Log also shows event horizons for paleoearthquakes PE3, PE2 and PE1.

Soft-sediment deformation features locally disrupt unit 5 in trench 2 (see trench 2 log, southeast wall, Plate 1a). Stratigraphic relationships indicate that these features post-date paleoearthquake PE3 but pre-date PE2, and thus occurred between about 12.7 ka and about 5.9 ka (discussed below). The liquefaction features apparently are related to strong ground motion produced by some other fault in the region.

Two paleoearthquakes occurred during the past 12,700 cal B.P. based on additional age control and trench relationships. Paleoearthquake PE2 faulted units 5 and 4 approximately 20 to 25 cm down to the southwest and opened a fissure that was subsequently infilled with fissure-fill unit FF2 (Figure 6; plate 1a). The event clearly postdates the Channel-A volcanic ash that we tentatively correlate to the 7,627 ± 150 yr BP Mt. Mazama ash, or the slightly older Tsoyowata ash (~7.8 ka). However, detrital charcoal from overlying unit 4 yields an AMS radiocarbon date of 8,990 to 8,610 cal yr BP (Table 1). This apparent stratigraphic inversion suggests that the detrital charcoal has a substantial residence time in this setting and was reworked, or alternatively, our tephra correlation may not be correct. Because PE2 offsets a channel containing the Mt. Mazama or Tsoyowata tephra, the event occurred sometime after ~7.8 ka (Figure 7).

The most recent event, PE1, offset units 3 and 2 30-32 cm and opened a fissure that was subsequently filled with unit FF1. The event triggered deposition of scarp-derived colluvium C1 proximal to the fault, which grades downward into the fissure fill deposit FF1. AMS radiocarbon dating of charcoal fragments collected from unit FF1 yield ages ranging from 2,324 to 1,960 cal yr B.P. (Table 1). This age range is derived from detrital charcoal fragments that may have a substantial residence time in this setting, so PE1 is likely to have occurred at or after ~2.3 ka. A late Holocene age for the most recent event is consistent with the lack of soil development in overlying alluvial (and aeolian?) unit 1.

In summary, trench exposures reveal that the eastern strand of the MVFZ has ruptured repeatedly during the latest Quaternary. A latest Pleistocene event,

PE3, ruptured the fault after about 40 ka and prior to about 12.7 ka, and was followed by two Holocene events, one after ~7.8 ka and the other around or after 2.3 ka (Figure 7). This record suggests earthquakes occur on the order of every 4,000 to 6,000 years along the eastern strand of the MVFZ.

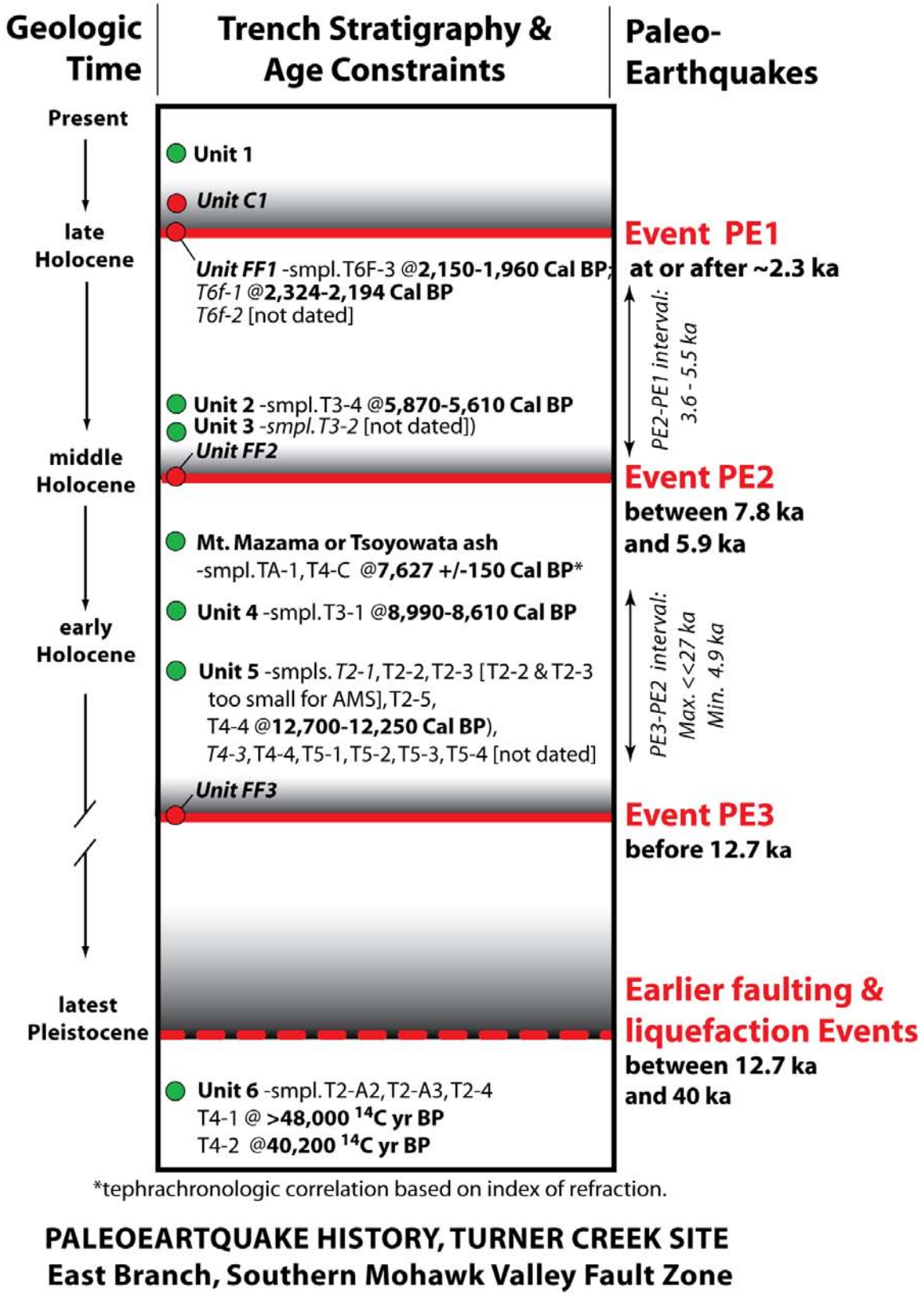

Figure 7. **Summary of eastern strand paleoseismic history.** Illustration shows relative stratigraphic position of trench units and age-control samples, including available age-dating results, in relation to a sequence of 3 paleoearthquakes interpreted from trench exposures at the Turner Creek trench site.

Minimum slip rate

The geomorphic expression and Turner Creek site trench exposures reveal right-lateral strike-slip faulting with a subordinate vertical component that varies in character along strike. We identified a faulted and buried paleochannel, which we call Channel A (Plates 1a and 1b). The channel contained reworked tephra T4-C (Plate 1a) and was expressed as a well-defined feature clearly inset into unit 5. Multiple exposures and total-station surveys provided three-dimensional control on the relationship of the fault to distinctive Channel A and we can confidently correlate and trace the paleochannel across the fault. We excavated numerous hand-dug exposures (e.g., Plate 1b) to trace the western margin of the channel directly to its intersection with the fault on both sides of the structure in an attempt to minimize uncertainty associated with projections.

Channel A is deflected southeastward obliquely along the fault scarp produced during paleoearthquake PE3. Subsequently, the paleochannel was displaced approximately 2.5-2.9 m right laterally (Figure 8) and approximately 0.5 to 0.75 m vertically during the two most recent paleoearthquakes, PE2 and PE1.

The age of Channel A can only be loosely constrained. The channel is younger than 12.7 ka, the age obtained from AMS sample T4-4 (Figure 7) from underlying unit 5. The extensive and distinctive lens of tephra contained in the channel is inferred to be the Mazama or the slightly earlier Tsoyowata tephra based on its refractive index of 1.510 and its stratigraphic position relative to other AMS radiocarbon dates. The tephra is obviously reworked, and thus it provides a maximum age of ~7.8 ka (Tsoyowata age) for the channel. The minimum age of the channel is ~5.7 ka, the age of sample T3-4 from overlying unit 2 (Figure 7).

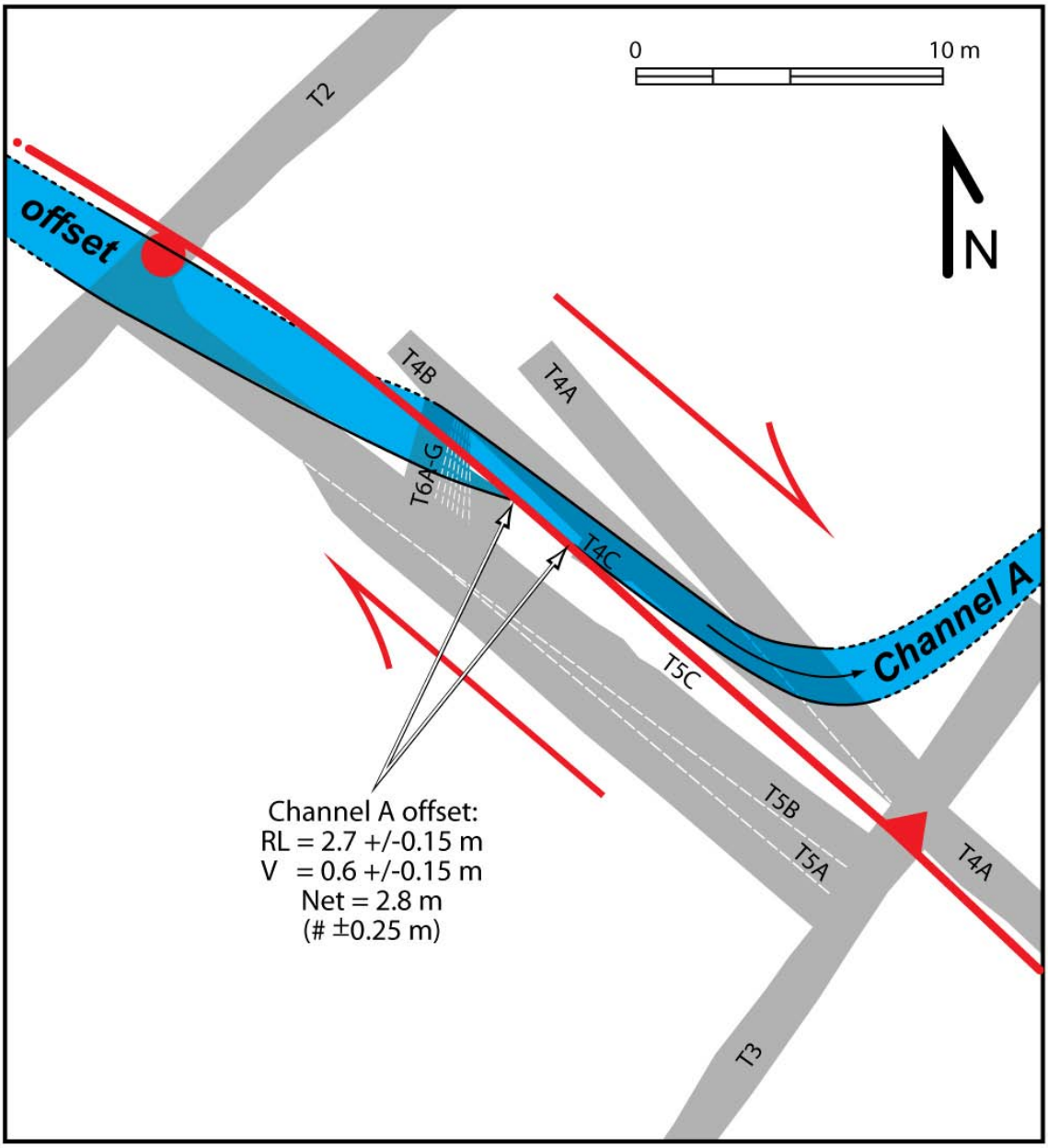

Figure 8. Map of Channel A across fault. Map showing the distribution and geometry of Channel A across fault exposed at the Turner Creek trench site, based on total-station surveys, supplemented with measurements made using leveling lines anchored to survey monuments and a measuring tape.

The net offset (2.8 ± 0.25 m) and available age constraints on Channel A (7.8 to 5.7 ka) provide a rate of right slip on the trenched strand of 0.4 ± 0.1 mm/yr.

Discussion

Our paleoseismic investigation demonstrates that the Mohawk Valley fault zone is a Holocene-active strike slip fault of the northern Walker Lane. Similar to other strike slip faults in the region, for example the Honey Lake, Warm Springs Valley and Pyramid Lake fault zones (Wills and Borchardt, 1993; Gold et al., 2013b; Briggs and Wesnousky, 2004; Turner et al., 2013), the most recent event on the Mohawk Valley fault zone occurred during the late Holocene, approximately 2,000 years ago or later. These events produced surface offsets up to about 1.5 m laterally and about a third of a meter vertically near the southern end of the eastern strand of the fault zone, comparable to most-recent-event offsets documented near the west end of the Olinghouse fault (Briggs and Wesnousky, 2005).

Geodesy suggests that the lateral slip rate may be as high as approximately 3 mm/yr across the Mohawk Valley fault zone (Hammond et al., 2011). Our study identified a latest Pleistocene to early Holocene buried channel laterally offset nearly 3 m along a continuous trace of the eastern strand, yielding a Holocene slip rate of 0.4 $\pm$ 0.1 mm/yr. However, this rate likely underestimates the overall rate of slip on this fault system for several reasons. First, our excavation captures deformation along a single strand of a broadly-distributed system. Second, the rate was determined near the south end where displacements are decreasing and die out less than 2 km to the southeast (Figure 2). Third, the channel is not an ideal piercing point, due to its substantial deflection along the fault scarp, and our calculation of offset and associated errors might be influenced slightly by channel geometry. Fourth, the offset feature appears to integrate offset from only two earthquakes. Finally, the slip rate we obtain on the eastern strand does not account for the predominately right-slip component previously demonstrated along the range-front strand (Sawyer et al., 1992; Sawyer and Briggs, 2001), and thus certainly underestimates the overall rate across the entire width of the highly distributed southern Mohawk Valley fault zone.

4. SUMMARY

The Mohawk Valley fault zone is a Holocene-active strike slip fault of the northern Walker Lane. Our study focused on the eastern strand, which is predominantly a right-slip fault expressed by low linear fault scarps in Sierra and Mohawk valleys.

Our mapping of the fault trace from small scale stereoscopic airphotos shows that the MVFZ forms a distributed, discontinuous but generally overlapping fault zone 60-70 km, or more, long, generally consisting of 3 structural elements or strands. The western strand appears to step right to the eastern strand across Mohawk Valley, apparently forming a Quaternary pull-apart basin or tectonic trough. The eastern and northern strands appear to form a left stepover that coincides with inferred contractional structures in Long Valley near Sloat. Similarly contractional structures are inferred where the fault zone intersects the Sierra Nevada-Cascade Range boundary zone in eastern American Valley. These observations and the overall geomorphic expression of the fault zone are consistent with predominantly right-slip on the MVFZ.

Stratigraphic relationships and available radiocarbon age constraints at the Turner Creek site document a sequence of three paleoearthquakes along the eastern strand during the latest Quaternary. The earliest paleoearthquake occurred after 40 ka and prior to 12.7 ka, the penultimate event occurred after 7.8 ka, and the MRE occurred around or after 2.1 ka. The site was subjected to earthquake-induced liquefaction between 12.7 ka and about 7.8 ka.

The activity of the eastern strand of the MVFZ demonstrated in the present study appears to be generally similar to preliminary constraints on the paleoseismicity activity of the western strand. However, the most recent event on the eastern strand may be younger than that on the western strand. For example, Sawyer et al. (1993) and Sawyer and Briggs (2001) showed evidence for 4 to 6 surface-faulting events during the late Quaternary at a site on the compound range-front escarpment west of Calpine and about 7 km west of the

Turner Creek trench site (Figure 2). The most recent event probably occurred during the Holocene, prior to 3,798 to 3,522 cal yr BP and possibly before 5,607 to 5,221 cal yr B.P. (based on our calibration of previously reported radiocarbon dates). Similarly, Gold et al. (2013a) reported evidence for 3 to 4 surface-faulting events based on offset latest Pleistocene to possibly Holocene stratigraphy exposed in three fault-normal trenches at the Sulphur Creek sidehill bench site, approximately 3.1 km northwest along the western strand in southern Mohawk Valley (Figure 2).

Trench exposes at the Turner Creek site permit us to confidently correlate a laterally restricted paleochannel across the fault. The precise geometry of the buried channel shows 2.7 ± 0.2 m right lateral offset and about 65 to 75 cm vertical offset, resulting in a net displacement of 2.8 ± 0.25 m. Displacement of Channel A occurred after paleoearthquake PE3 and records progressive offset accompanying paleoearthquakes PE2 and PE1. The age of the channel is 7.6 to 5.7 ka, if the ages we infer for the prominent tephra incorporated in channel deposits are correct. The geometry and age of the offset channel provide a basis for estimating a rate of late Holocene right slip along the eastern strand of 0.4 ±0.1 mm/yr.

This slip rate estimate is relevant to one fault trace of the eastern strand, and does not account for right slip along the western strand or along potentially unidentified strands elsewhere. Thus, the rate represents the lower bound or limiting-minimum rate of right slip across the entire width of the southern Mohawk Valley fault zone; the actual rate across the fault zone is likely to be higher. Finally, if characteristic earthquake behavior is assumed, the two most recent events each produced ~1.5 m of net displacement at a site located near the southern end of the eastern strand.

5. REFERENCES CITED

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6. Table

TABLE 1
AGE-DATING SAMPLES AND RESULTS

Sample No. [1]	Lab. Sample No.	Trench Unit/Depth Below Surface	Type of Material	AMS Radiocarbon Date[2] (Conv. ^{14}C yr BP)	AMS Radiocarbon Date[2] (2 Sigma cal. BP)[3]	Remarks
T1-1	—	unit T1	volcanic tephra	—	7627 +/-150[4]	Refractive index of 1.510 correlates to Mt. Mazama ash; Predates event PE2 at trench 1
T2-1	—	unit 5	detrital charcoal	—	—	Provides potential to ~date age of offset channel A
T2-2	—	unit 5 1.45 m	detrital charcoal	—	—	Predates liquefaction features in unit 5, but too small for MS-AMS counting after pretreatment (w.c. Beta, 1/5/05)
T2-3	—	unit 5 1.25 m	detrital charcoal	—	—	Predates liquefaction features in unit 5, but too small for MS-AMS counting after pretreatment (w.c. Beta, 1/5/05)
T2-4	—	unit 6	detrital charcoal	—	—	Stratigraphically predates latest Pleistocene event(s)
T2-5	—	unit 6	detrital charcoal	—	—	Provides potential to ~date age of offset channel A

TABLE 1 (continued)

Sample No. [1]	Lab. Sample No.	Trench Unit/Depth Below Surface	Type of Material	AMS Radiocarbon Date[2] (Conv. ^{14}C yr BP)	AMS Radiocarbon Date[2] (2 Sigma cal. BP)[3]	Remarks
T3-1	Beta-198557	unit 4 0.85 m	detrital charcoal	7,920 ± 40	8,990 to 8,610	Stratigraphically predates event PE2 and post-dates event PE3; few small charcoal fragments
T3-2	—	unit 3 0.58 m	detrital charcoal	—	—	Stratigraphically predates event PE1/MRE and post-dates event PE2; few very small charcoal fragments
T3-4	Beta-198558	lower unit 2 0.40 m	detrital charcoal	4,980 ± 40	5,870 to 5,610	Stratigraphically predates event PE1/MRE and post-dates event PE2
T4-1	NOSA MS-116786	unit 6 1.60 m	detrital wood & charcoal	>48,000	—	Stratigraphically predates latest Pleistocene event PE3. Sample exhibits no radiocarbon activity (i.e., 'radiocarbon dead').
T4-2	NOSA MS-116789	unit 6 1.95 m	detrital wood & charcoal	40,200 ±520	—	Stratigraphically predates latest Pleistocene event PE3. Sample exhibits very little radiocarbon activity.
T4-3	—	unit 5	detrital charcoal	—	—	Potential to constrain maximum age of offset channel A; Stratigraphically predates event PE3 and post-dates earlier event(s)
T4-4	LLNL	lower unit 5 1.22 m	detrital charcoal	10,505 ± 40	12,700 to 12,250	Potential to constrain maximum age of offset channel A; Stratigraphically predates event PE2 and post-dates earlier event(s)

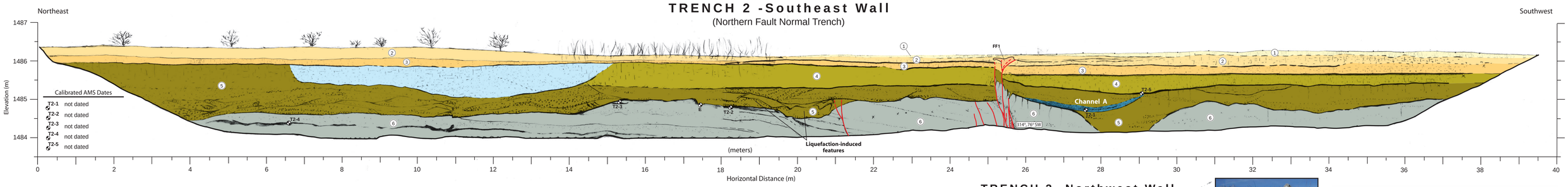
TABLE 1 (continued)

Sample No.[1]	Lab. Sample No.	Trench Unit/Depth Below Surface	Type of Material	AMS Radiocarbon Date[2] (Conv. ^{14}C yr BP)	AMS Radiocarbon Date[2] (2 Sigma cal. BP)[3]	Remarks
T5-1	—	unit 5 2.1 m	detrital charcoal	—	—	Stratigraphically predates latest Pleistocene event PE3
T5-2	—	unit 5 1.65 m	detrital charcoal	—	—	Stratigraphically predates latest Pleistocene event PE3
T5-3	—	unit 5 1.6 m	detrital charcoal	—	—	Stratigraphically predates latest Pleistocene event PE3
T5-4	—	unit 5 1.7 m	detrital charcoal	—	—	Stratigraphically predates latest Pleistocene event PE3
T6f-1	NOSA MS-116788	unit FF1	organic-rich layer	2,250 ±30	2,324 to 2,194	Provides ~date of PE1/MRE, ignoring any mean residence time.

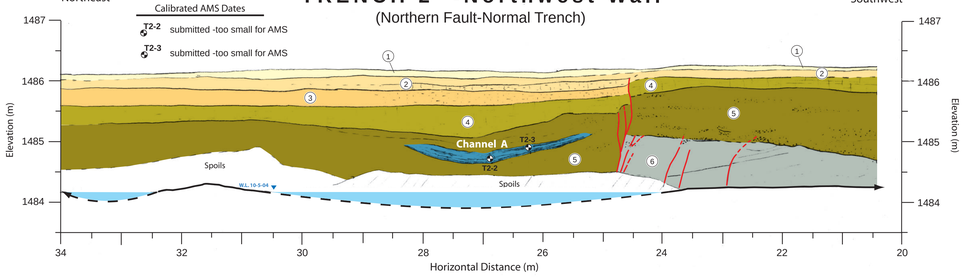
TABLE 1 (continued)

Sample No.[1]	Lab. Sample No.	Trench Unit/Depth Below Surface	Type of Material	AMS Radiocarbon Date[2] (Conv. ^{14}C yr BP)	AMS Radiocarbon Date[2] (2 Sigma cal. BP)[3]	Remarks
T6f-2	—	unit FF1	detrital charcoal	—	—	Potential to ~date event PE1/MRE; single very small charcoal fragment (too small for AMS?)
T6f-3	Beta-198559	unit FF1	organic-rich layer	2,090 ± 40	2,150 to 1,960	Provides ~date of PE1/MRE, ignoring any mean residence time.

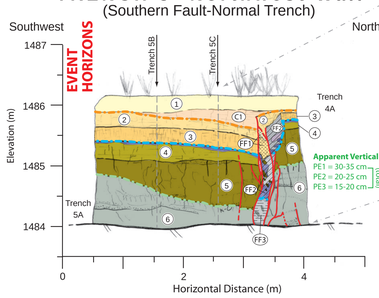
TRENCH 2 -Southeast Wall
(Northern Fault Normal Trench)



TRENCH 2 -Northwest Wall
(Northern Fault-Normal Trench)



TRENCH 3 -Northwest Wall
(Southern Fault-Normal Trench)



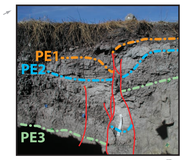
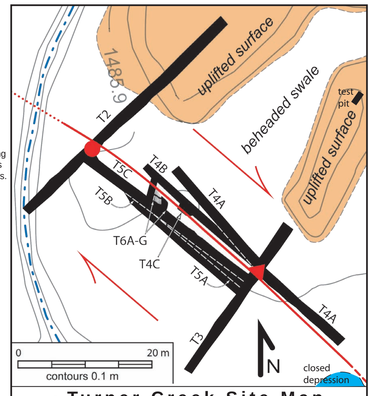
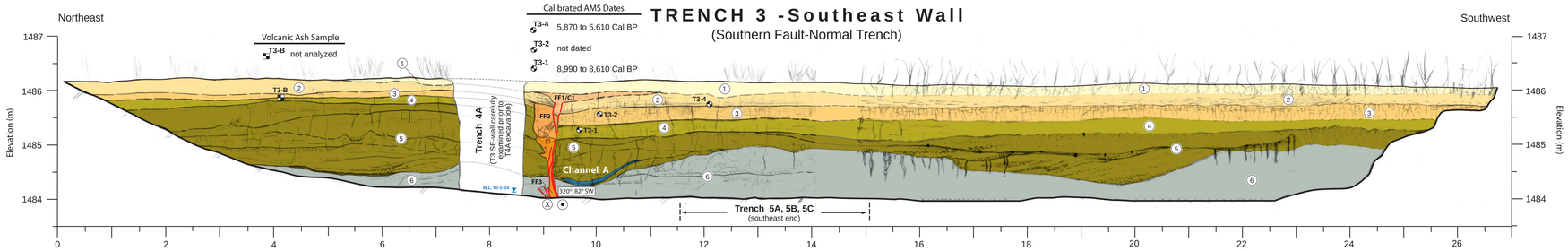


Photo of northwest wall of trench 3 showing fault zone and key stratigraphic markers or paleo-earthquake (PE) event horizons.

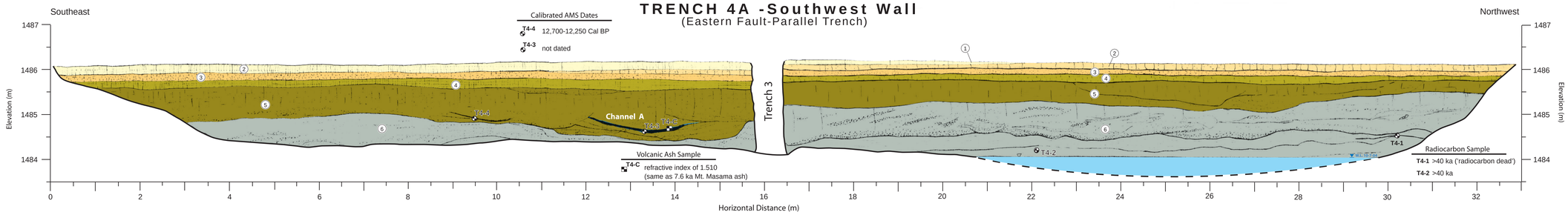


Turner Creek Site Map
(See Figure H for explanation)

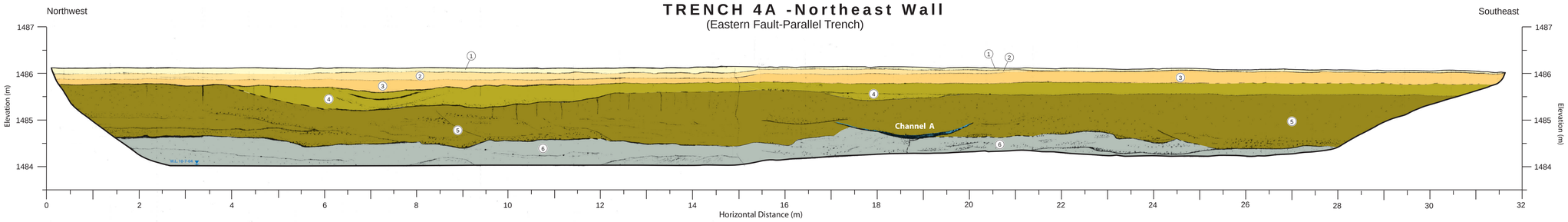
TRENCH 3 -Southeast Wall
(Southern Fault-Normal Trench)



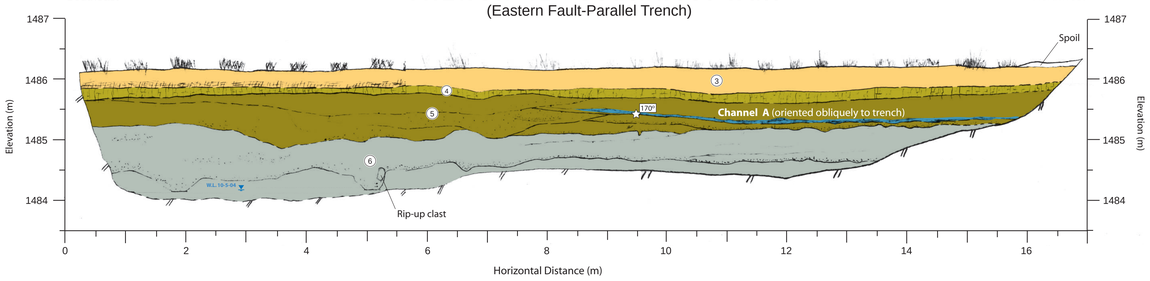
TRENCH 4A -Southwest Wall
(Eastern Fault-Parallel Trench)



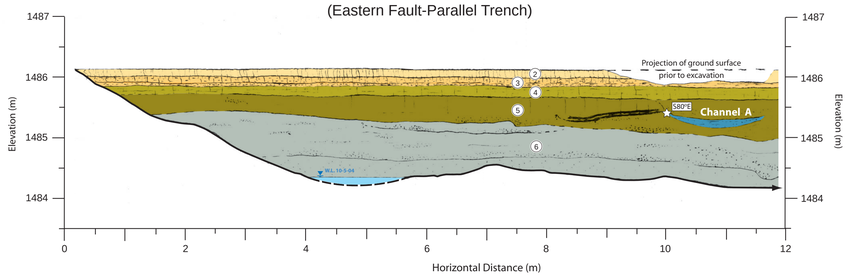
TRENCH 4A -Northeast Wall
(Eastern Fault-Parallel Trench)



TRENCH 4B -Southwest Wall
(Eastern Fault-Parallel Trench)



TRENCH 4B -Northeast Wall
(Eastern Fault-Parallel Trench)



NOTES: For graphical log of trench 1, see Figure 5.
For explanation and description of trench units, see Plate 1b.
Graphical trench logs are geometrically constrained by total station surveys, having a common coordinate system.
Absolute elevations provided by differential GPS survey.

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TURNER CREEK SITE TRENCH LOGS
Paleoseismic Investigation of the Mohawk Valley fault zone, Sierra Valley, Northeastern California

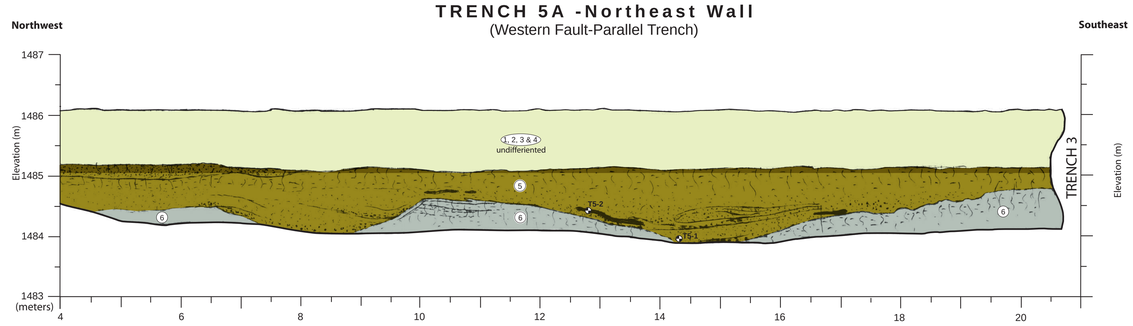
BY	SCALE	PROJECT NO.
TS, AR, RB	1" = 1m	1098
APPROVED BY	DATE	PLATE NO.
TS, RB, AR	November, 2013	1a

(Site UTM coordinates: 722945, 4392325)

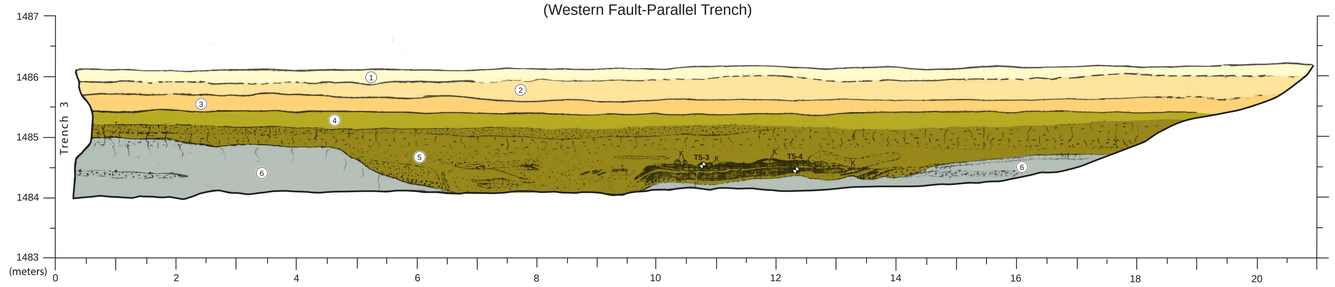
EXPLANATION

- -depositional contact
- -fault
- -fracture
- -blocky soil structure
- K -Krotovina
- T4-4 -Radiocarbon sample
- T3-b -Tephra sample

TRENCH 5A -Northeast Wall
(Western Fault-Parallel Trench)



TRENCH 5A -Southwest Wall
(Western Fault-Parallel Trench)



TRENCH STRATIGRAPHY

Alluvial Units

Unit 1—Consists of black, organic-rich silty clay that is slightly sticky, plastic when moist and displays large subangular blocky soil structure. Unit 1 forms the surficial (youngest) layer of alluvium that overlies unit 2 and, locally, units C1 and FF1. Although unit predominantly exhibits an alluvial character, it likely incorporates aeolian fine grain materials. Unit 1 is up to a third of a meter thick and generally thickens away from the fault trace to the southwest, but locally is absent on the northeast or relatively upthrown side of the fault.

Unit 2— Consists of whitish to light gray, organic-rich diatomaceous earth and clay that is slightly sticky and plastic when moist and exhibits subangular blocky to prismatic soil structure, but lack sedimentary structure (i.e., is massive). Unit 2 is up to about 35 cm thick and is generally present throughout the site, except locally on the northeast or relatively upthrown side of the fault. Unit 2 depositionally overlying unit 3 and, in trench 3, is in fault contact with units C1 and FF1. Unit 2 generally thickens, locally fairly abruptly, away from the fault to the southwest.

Unit 3—Dark gray, organic-rich clay that is sticky and plastic when moist and exhibits moderate subangular blocky and compound columnar soil structures, but otherwise is a massive alluvial deposit. The alluvial deposits ranges from less than a decimeter up to about 45 cm thick, and generally is thickest on the southwest or relatively downthrown side of the fault. Unit 3 is present throughout the site, including underling the relatively uplifted alluvial surfaces northeast of the fault (e.g., Figure sitemap). Unit 3 overlies unit 4 and is in fault contact with units FF1, 4, and FF2.

Unit 4—Similar to unit 3, unit 4 is composed of dark gray, organic-rich clay that is sticky and plastic when moist and exhibits moderate subangular blocky and compound columnar soil structures. Rather than massive, however, unit 4 exhibits sedimentary structure consisting of alternating dark and light gray sedimentary layers. Unit 4 is generally present throughout the site and has a rather uniform thickness of about 20 to 30 cm, but thickens to more than 80 cm near the northeast end of trench 2 where this unit includes a comparatively large channel form and associated channel-fill sequence with distinct internal stratification. Unit 4 overlies unit 5 and is overlain by unit 3. In trench 2, unit 4 is in fault contact with unit 3 and, in trench 3, with fissure-fill unit FF2.

Unit 5—Consists of light gray to light yellow, where oxidized, non-sticky and non-plastic, fine to medium sand with abundant internal alluvial stratification and, in upper 20-30 cm, generally displays subangular blocky soil structure. This alluvial sequence is up to nearly 2 m thick and exhibits internal channelization and locally cross bedding. The alluvial channels typically are 1.5 to 2.5 m wide and less than a 1 m deep. Some channel forms (e.g., Channel A) are marked by distinctive light gray diatomaceous layers and finning-upward grading. Unit 5 contains one channel, Channel A, that we confidently correlate across the fault (see discussion in report). The unit locally exhibits evidence for soft-sediment deformation that we attribute to a seismically induced liquefaction event, independent of the sequence of 3 paleoearthquakes documented in this study (see report text). In trenches 2 and 3, unit 5 is in fault contact with units 6 and FF3.

Unit 6—Consists of orange to bright yellow clay that is sticky and plastic when moist, and displays strong subangular blocky structure. The alluvial deposit also exhibits internal stratification, including sandy interbeds of variable thickness, that locally have been offset across minor faults and shears or modestly tilted and/or warped. We largely or entirely attribute this internal deformation to be the result of an event(s) that predate the sequence of 3 paleoearthquakes documented in this study (see text in report). The base of unit 6 was not exposed, so its thickness of this alluvial deposit is unknown. Unit 6 is in fault contact with unit 5 in trench 2 and with various fault-proximal units in trenches 3 and 6.

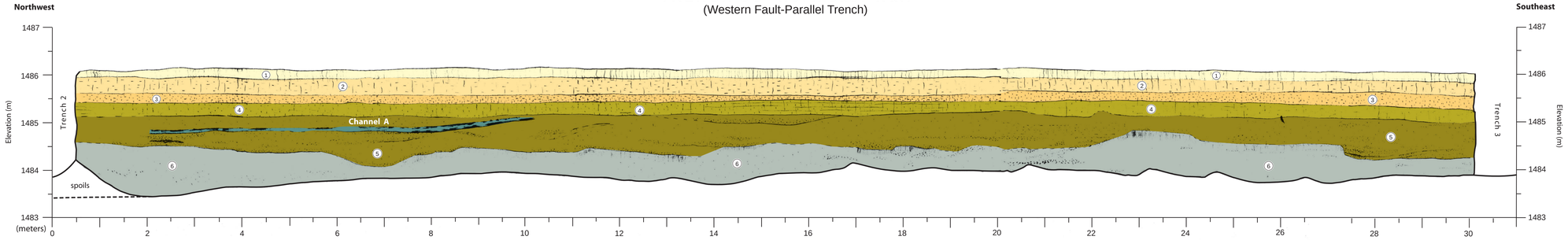
Fault-Proximal Units

Unit C1/FF1—Consists of white, black, light gray and light brown layers of silty clay that is very sticky, plastic and exhibits large subangular blocky peds. Colluvial unit C1 is exposed in the northwest wall of trench 3 as a generally southwest-thinning wedge of colluvium, up to about 20 cm thick, overlying unit 2 and in contact with unit 2 along an exposed fault plane or, as described below, a paleo-freeface contact. Unit C1 is similarly exposed in the opposite trench wall, where, in addition, it forms a downward-tapering wedge within the uppermost exposed fault zone, designated sub-unit FF1. Here the sub-unit is floored by a downdropped piece of unit 2. In addition fissure-fill sub-unit FF1 was exposed in the southeast wall of trench 2, but was not identified in the opposite wall, suggesting the fault fissure was discontinuous at this location. These are the youngest unfaulted deposits exposed at the Turner Creek site.

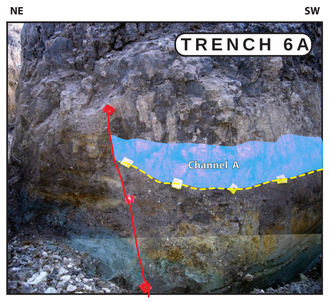
Unit FF2—Consists of a non-stratified chaotic mix of irregular aggregates derived from units 3 and 4 within a sandy silt matrix. Fissure-fill unit FF2 is exposed in trench 2 as a fractured, fault bounded package 60 cm thick and about 45 cm wide. Unit FF2 is internally faulted and is in fault contact with units 3, 4 and 5, and is in 'freeface-contact' with unit FF1. The fissure-fill debris is in depositional contact with units 3 and 4 as a result of scour evidently resulting from a minor drainage 'captured' by the fissure. Unit FF2 is overlain by unit 2.

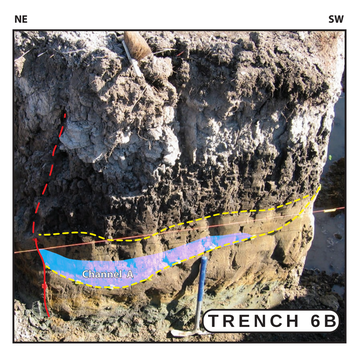
Unit FF3—Consists of a non-stratified chaotic mix of irregular aggregates derived from unit 4 within a sandy silt matrix, exhibiting crude stratification near northeast margin of unit. Fissure-fill unit FF3 is up to 35 cm wide and extends to the bottom of trench 2 and 3 exposures. The package has been internally faulted and is in fault contact with unit 5 on the southwest, but is in depositional contact with the same unit on the northeast as a result of scour evidently by a minor drainage that temporarily occupied the fissure. Unit FF3 is overlain by unit FF2 in depositional contact.

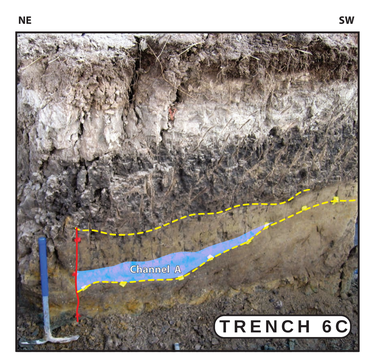
TRENCH 5C -Northeast Wall
(Western Fault-Parallel Trench)

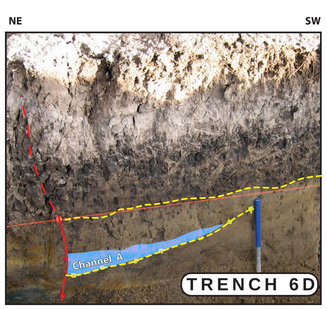


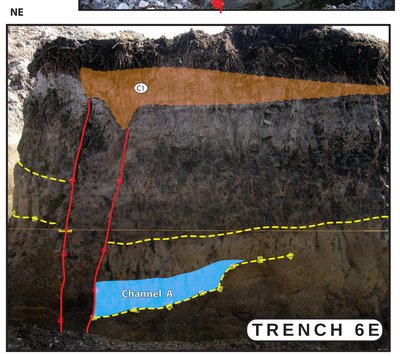
ANNOTATED PHOTO-LOG OF TRENCH 6 EXPOSURES
-Southast Wall of Exposures
(Central Fault-Normal Trench)





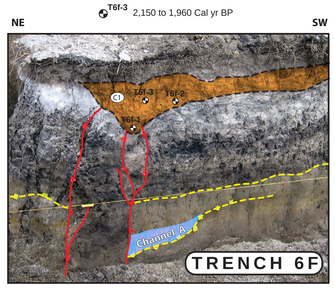


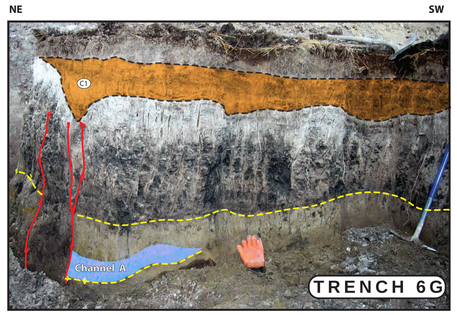




Calibrated AMS Date

- T6f-1 2,250 Cal yr BP
- T6f-3 2,150 to 1,960 Cal yr BP





NOTES: Trench 5 graphical trench logs are based on total station surveys, having a common coordinate system, with absolute elevation provided by the differential GPS site survey. Trench 6 logs utilized level-line datum tied into total-station survey points (nails).

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TURNER CREEK SITE TRENCH LOGS

Paleoseismic Investigation of the Mohawk Valley fault zone, Sierra Valley, Northeastern California

BY	SCALE	PROJECT NO.
TS, AR, RB	1″= 1m	1098
APPROVED BY	DATE	PLATE NO.
TS, RB, AR	November, 2013	1b