U.S. Geological Survey Earthquake Hazards Reduction Program

Final Technical Report

Spatial and Temporal Patterns of Fault Slip Rates on the Genoa Fault

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Abstract

In this study, we conducted the first paleoseismic work on the southern part of the Genoa fault, one of the most active faults in the Basin and Range Province. From two trenches excavated across Holocene fault scarps at Fay Canyon, we have high confidence that the southern Genoa fault ruptured with the central part of the fault, and we infer that ruptures extended at least as far south as Woodfords. At Fay Canyon, displacements were significantly smaller (~1 m/event) than along the central part of the fault (~5 m/event); this decrease in displacement appears to occur across a 1 km stepover at Jobs Canyon, just north of Fay Canyon.

Dating results from the Fay Canyon trenches indicate that the two most recent surface-rupturing events occurred somewhat more recently than previously reported. We now believe the most recent event occurred about 300 years ago, and that the penultimate event occurred about 1700 years ago, both ages being 200-300 years younger than prior estimates. Much, if not all, of the Carson Range frontal fault system ruptured at both of these times, but we do not have the resolution to conclude whether this occurred as 100-km-long ruptures, which would be unusual, or as multiple, temporally grouped (i.e., likely triggered) events.

This study was originally submitted as a collaborative project with Dylan Rood. The two parts of the project were ultimately funded separately, but the work was still done cooperatively and Rood was heavily involved in the trench studies. Rood's work under his own study, including estimation of longer-term slip rates, is contained in a separate report.

Introduction

The Genoa fault, which bounds the prominent eastern front of the Carson Range, is one of the most active faults in the Basin and Range Province. As discussed here, the Genoa fault is the main part of the Carson Range fault system (CRFS), a 100-km-long, east-dipping frontal fault of the Sierra Nevada/Basin and Range transition zone (fig. 1). The CRFS poses the principal seismic hazard to the Reno/Carson City urban corridor of western Nevada.

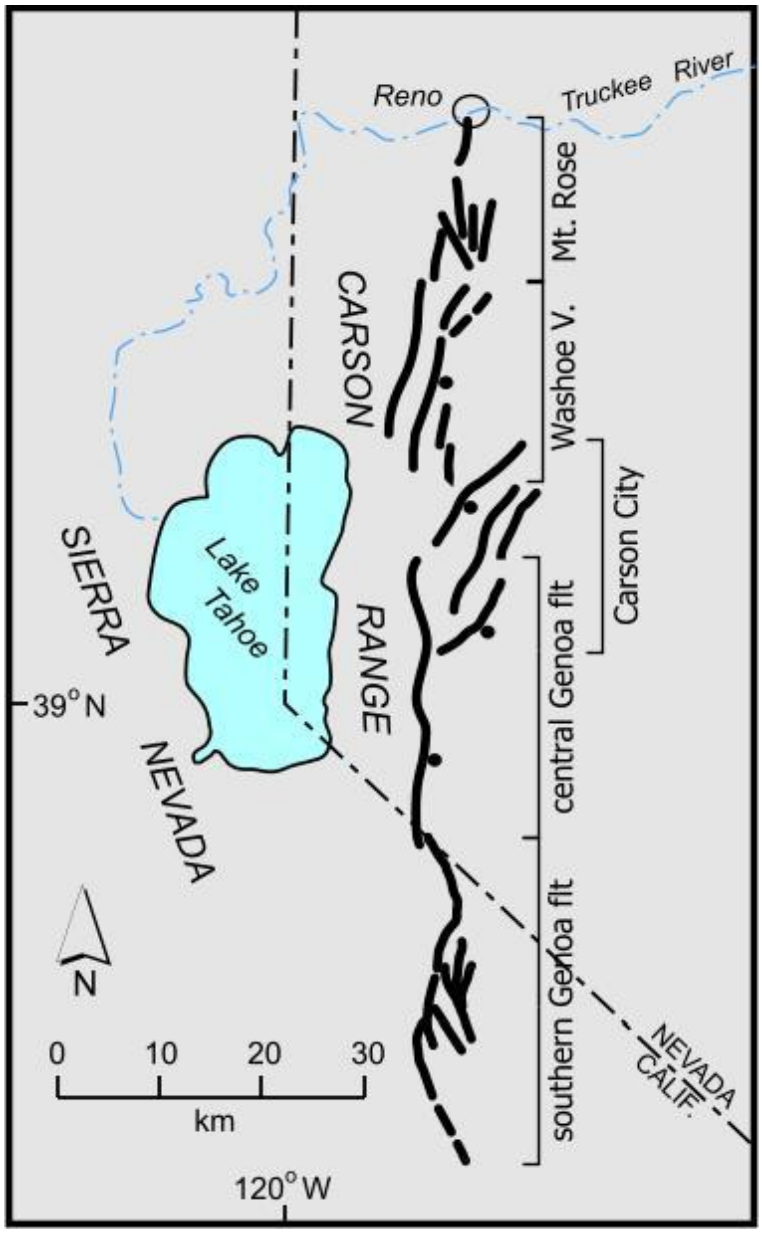

Figure 1. Generalized strip map of the Carson Range fault system, with sections divided based on structural discontinuities. The Genoa fault forms the main, southern part of the system; three NE-striking faults (from south to north, the Indian Hills, Carson City, and Kings Canyon faults) comprise the Carson City section; and the distributed Washoe Valley and Mt. Rose sections form the northern part of the system.

Conspicuous fault scarps along the Genoa fault (fig. 2) have long led to speculation about the fault's recency (e.g., Lawson, 1912; Pease, 1983).

Figure 2. Shadowed fault scarp along the Genoa fault, north of Genoa, looking west. Jacks Valley is just off the photo to right. Photo by Jeremy Vlcan.

Paleoseismic studies conducted along the central part of the Genoa fault (fig. 3) during the 1990s showed that the fault has ruptured with large surface displacements (~5 m/event) at least twice during the late Holocene (Ramelli et al., 1999). However, the southern extents of these ruptures and the longer-term earthquake history remained poorly constrained.

In the vicinity of Jobs Canyon, the Genoa fault makes a left step of more than 1 km. To the south of this stepover, recent activity is less obvious: fault scarps are smaller and more subdued, and there is significantly less basin fill on the downthrown side of the fault. Nonetheless, similar to the central part of the fault, the southern part of the fault forms a steep range front along most of its length, recent ruptures have occurred primarily along a sharp bedrock/alluvial contact, and fault scarps in alluvium are generally present only at the mouths of major drainages.

The most obvious fault scarps along the southern Genoa fault are located at Woodfords (fig. 4; see also the southern part of fig. 3), where the fault cuts outwash terraces along the West Fork of the Carson River. These scarps indicate that the southern part of the fault is less active than the central part, but prior to this study, it remained unclear whether the southern part ruptures less frequently, or simply ruptures with smaller offsets.

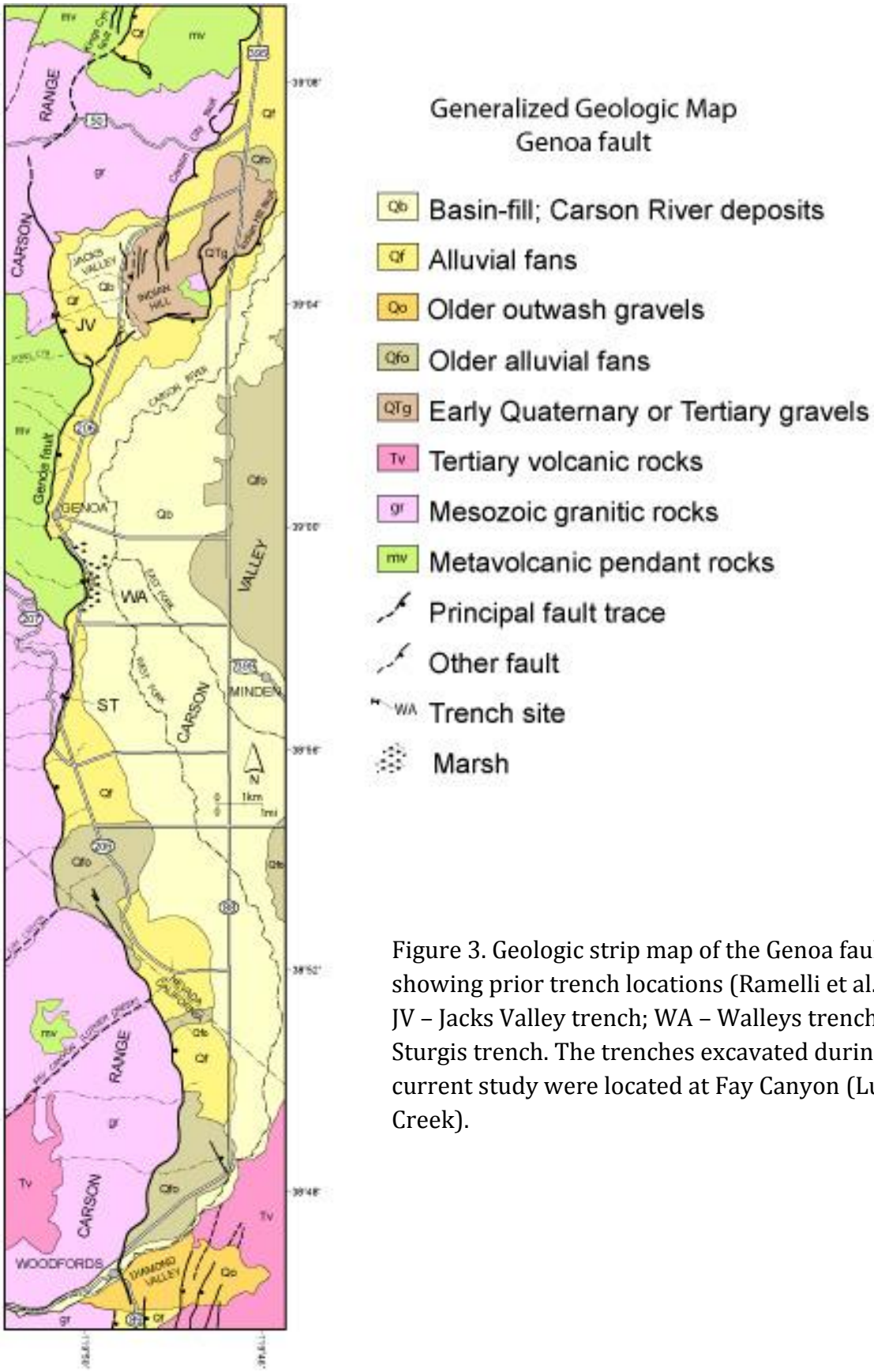

Figure 3. Geologic strip map of the Genoa fault, showing prior trench locations (Ramelli et al., 1999). JV – Jacks Valley trench; WA – Walleys trench; ST – Sturgis trench. The trenches excavated during the current study were located at Fay Canyon (Luther Creek).

The West Fork of the Carson River drains Hope Valley, which contained up to 300 m of ice during Late Pleistocene glacial periods (Armin and John, 1983). A prominent lateral moraine at Woodfords (fig. 4) indicates that a valley glacier extended down the West Carson River canyon during at least one glacial period (presumably Tahoe). The river canyon is currently more V-shaped than typical for a glacial valley, suggesting a period of downcutting since the canyon was glaciated.

Figure 4: Moraine of probable Tahoe age at Woodfords.

Clark et al. (1984) estimated a slip rate of about 1 mm/yr at Woodfords, based on an assumed late Tioga age for the youngest offset outwash surface. More recent work on these outwash terraces, including cosmogenic dating, indicates a slip rate of closer to 0.4 mm/yr (Rood et al., 2011).

The outwash deposits at Woodfords are very coarse, being dominated by boulders up to several meters in diameter. Unfortunately, the coarse nature of these deposits precludes conventional trenching methods at this location.

Objectives

In this study, we conducted paleoseismic studies of the southern part of the Genoa fault (i.e., that part of the fault located south of a 1 km left step at Jobs Canyon). We focused on the southern part of the fault for two primary reasons: 1) we hoped to determine whether the southern part of the fault ruptures with the previously studied central (main) part or whether it ruptures independently; and 2) we hoped to be able to extend the paleoseismic record beyond the two most recent events, which had proved difficult to accomplish along the central part of the fault due to the large displacements.

Considering the large displacements along the central section of the fault (~5 m per event), it is seems unlikely that ruptures are confined to the central section's relatively short length (~25 km). Offset deposits along the West Fork of the Carson River at Woodfords indicate the southern part of the Genoa fault has had Holocene activity, but recent fault scarps are much less obvious along the southern part of the fault. One possible explanation for the more subdued expression is that offsets are smaller than along the central part of the fault. A second explanation may be the predominance of easily eroded decomposed granite (grus) deposits.

One significant advantage of trenching smaller fault scarps is that it should be logistically more practical to expose a longer earthquake record. We had high hopes for being able to do just that, but this ultimately did not pan out.

This project was originally submitted as a collaborative proposal, with the other part (mainly an effort to estimate longer-term slip rates through fault scarp profiling and cosmogenic dating) headed by Dylan Rood (then at Lawrence Livermore Laboratories and UC Santa Barbara, and now at the University of Glasgow). Initially, only the trenching effort (this study) was funded, but Rood was able to obtain funding the following year under a stand-alone proposal, and this study was done cooperatively with Rood, as originally intended. Rood was heavily involved in all aspects of the trench study. He took on the unenviable chore of trench permitting, participated in trench interpretation and logging, and also did the radiocarbon analyses.

Fay-Luther trench site

We excavated two trenches across fault scarps with apparent progressive offsets at the mouth of Fay Canyon, one of the largest drainages along the southern Genoa fault (second only to the West Carson River Canyon). Fay Canyon is drained by Luther Creek, and both of these are commonly used place names. Following the nomenclature used for the trail system at this location, we refer to this as the Fay-Luther site.

A prominent fault scarp about 20 m high and 500 m long (fig. 5) crosses the broad Pleistocene surface at the mouth of Fay Canyon. This surface is largely comprised of debris shed from the unstable flank of Jobs Sister (i.e., north side of the canyon), which has forced the main drainage (Luther Creek) to the south side of the canyon (fig. 11). The resulting constriction of the drainage has hindered development of young alluvial surfaces on the upthrown side of the fault. For this reason, we selected smaller, and hence younger, fault scarps preserved along secondary drainages on the north side of the canyon mouth. The trench site is located at a relatively small, ephemeral drainage that sources from the southeast side of Jobs Sister and is thus tributary to Luther Creek.

Figure 5. Fault scarp in Pleistocene deposits at the mouth of Fay Canyon is about 20 m high. Trench site is located to the right of the photo. Photo looking SW from Fay-Luther trailhead.

We excavated trenches across fault scarps on two adjacent surfaces (fig. 6). One trench (FL2) was located across a 2 m high scarp, while the other (FL1) was located on a nearby 4 m high scarp. We initially suspected we would find offsets of 2 m/event, but trench relations showed that offsets at this location were closer to 1 m/event. That raised hopes of the 4 m scarp exposing a longer earthquake record; while earlier events may be recorded in the lower part of the trench, their relations were unclear.

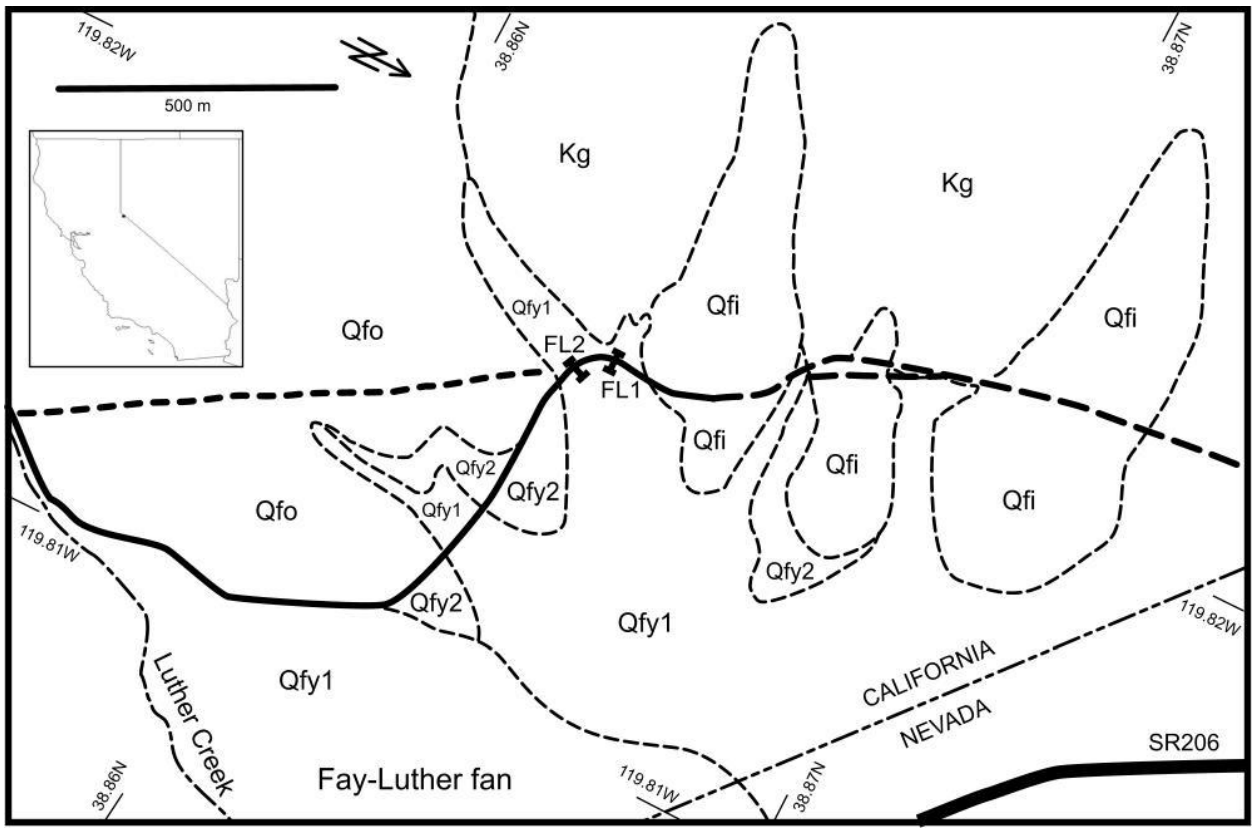

Figure 6. Generalized geologic map of the Fay-Luther trench site. Fault traces are shown by a solid line where well located; long dashes where approximately located; short dashes show an approximately located pre-Holocene fault trace. Qfy1 – late to middle Holocene alluvium; Qfy2 – early Holocene to late Pleistocene alluvium; Qfi – late Pleistocene alluvium; Qfo – probable middle Pleistocene alluvium; Kg – Cretaceous granodiorite.

Trenching was initially scheduled during June of 2011, but the Spring season of that year was unusually wet, and to top it off, we received more than one inch of rain just prior to the scheduled excavation. A shallow soil pit confirmed that surficial deposits were wet to a significant depth, which raised two concerns: 1) moisture would likely mask key relations, making trench interpretations less certain; and 2) saturated deposits are often less stable and thus pose greater safety concerns. We therefore decided to postpone excavation until the Fall of 2011. As it turned out, deposits were very dry when excavated, and lacking cohesion, the trench walls continuously raveled back while exposed. These conditions posed lesser safety concerns, but made trench interpretation quite challenging.

Deposits in both trenches, but especially trench FL1 (fig. 7), lacked any appreciable cohesion, and the trench walls quickly tried to ravel back to an angle of repose. In trench FL1, this problem was bad enough that each day presented an essentially new exposure. Shoring the trenches would only have exacerbated this problem, so they were left unshored with benches cut in the north walls. The instability of the trench walls posed considerable challenges in interpreting and logging the trenches. Conventional gridding would have been impractical, and total-station surveying was unrealistic because flagged nails wouldn't stay in place long enough. Fortunately, Rood and others from UC Santa Barbara were conducting ground LiDAR surveying of the site at the time, and they were able to scan the trench walls. Almost immediately after the LiDAR scan was completed, much of the flagged wall of trench FL1 sloughed off. While not ideal, we were able to log from LiDAR scans overlaid on photos. This worked fairly well, but we found the ends of the trenches to be poorly constrained. To compensate for this, the trench logs shown here (Plates 1, 2) were adjusted to fit surface profiles. This adds some uncertainty to offset estimates, but has no impact on interpretation of event relations. We hope the logs can be refined with additional LiDAR processing, so the logs shown here are somewhat generalized.

Figure 7. Photo of trench FL1 showing the loose sandy nature of the exposed deposits. Gently dipping stratified fan deposits can be seen in the upper end of the trench. Dips parallel to the scarp slope were initially interpreted as scarp colluvium, but radiocarbon ages indicate an age similar to the upper fan deposits and therefore suggest they are actually fan deposits that draped a preexisting scarp.

Trench FL1

Trench FL1 was excavated in a small alluvial fan (fig. 8) that is tributary to the drainage where trench FL2 was located (see fig. 6). Given the smaller source area, we hoped that trench FL1 would expose more thinly bedded deposits, therefore possibly providing better constraints on offsets and event relations. We also hoped that the larger (~4 m high) scarp would expose a longer paleoseismic record. Ultimately, the former held true, although a much broader distributed fault zone added uncertainties to interpretation of offsets and event relations. The trench only provided clear constraints on the two most recent events, but it nonetheless yielded a wealth of radiocarbon age control and helped tighten constraints on event ages.

Figure 8. Beginning excavation of trench FL1. The 4 meter high scarp crosses a small alluvial fan that is tributary to the drainage where trench FL2 was located.

Trench FL1 (figs. 7, 9; Plate 1) exposed thinly to moderately bedded, moderately sorted alluvial fan deposits in the footwall, a broad distributed fault zone, poorly preserved colluvial wedge deposits, and abundant detrital charcoal. Most of the exposed deposits are quite similar to each other, and they were therefore difficult to correlate. Within the fault zone, the deposits generally have scarp-parallel dips and in places are better sorted than the footwall deposits; we therefore initially interpreted that the deposits within the fault zone were, at least in part, colluvial deposits related to surface offsets. However, dating results suggest that these are mainly fan deposits draped across a preexisting fault scarp. A thin deposit burying the toe of the scarp contains large

clasts that are not seen elsewhere in the trench, and therefore appears to be an interfingering deposit associated with the main drainage.

In stark contrast to the singular fault in trench FL2, trench FL1 exposed a 10-m-wide distributed fault zone. Individual fault strikes ranging from 315° to 340° were somewhat oblique to the trend of the scarp at this location, suggesting surface rupture occurred as *en echelon* breaks due to the curving fault trace (refer to fig. 6). Fault relations in trench FL1 were therefore much less clear than in trench FL2.

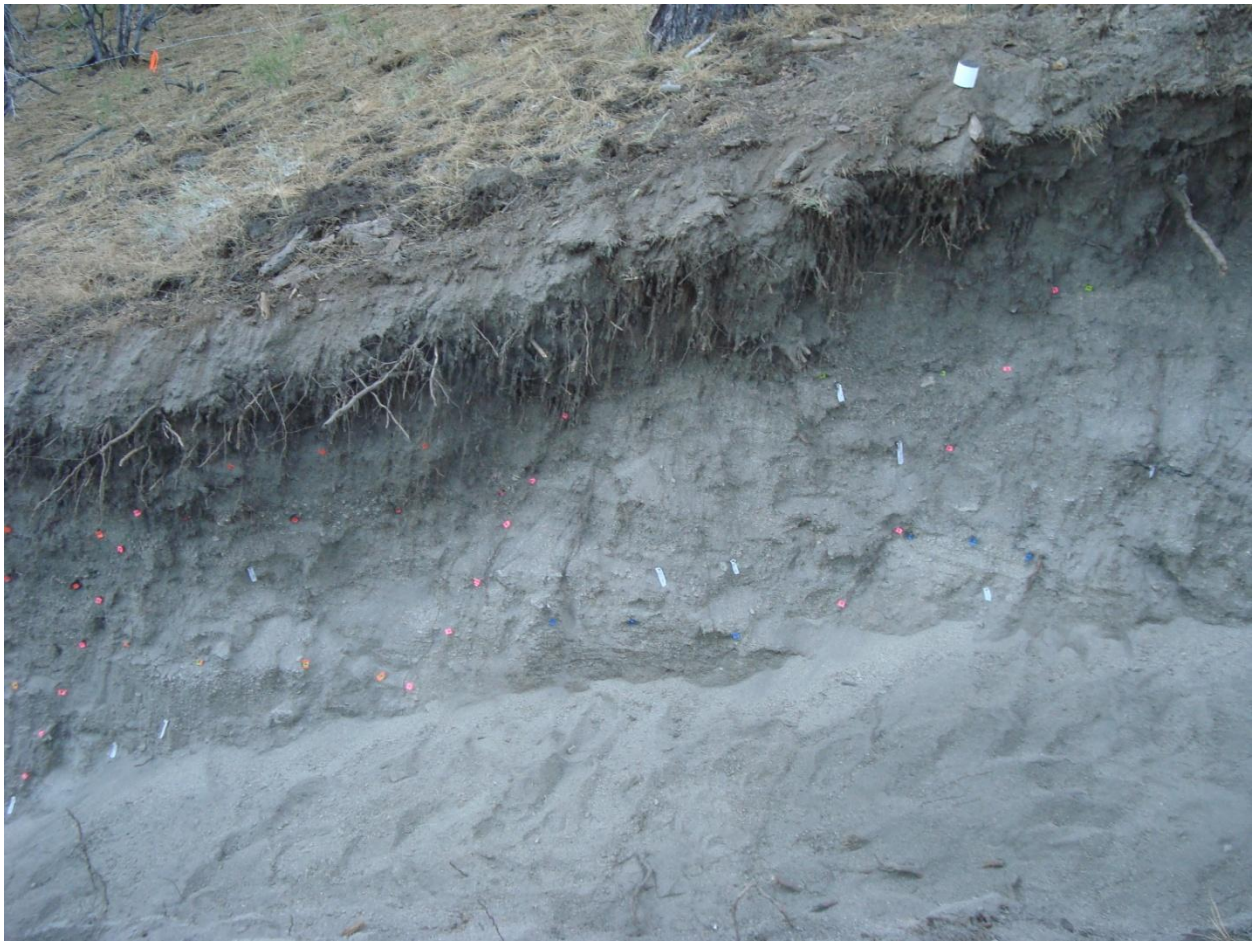

Figure 9. Photo showing distributed fault zone in trench FL1.

We collected almost 50 charcoal samples from trench FL1 (Table 1; Plate 1), but we did not focus on constraining the MRE in this trench because relations were much clearer in trench FL2. Of nine FL1 samples analyzed, seven were interpreted as being between the MRE and PE event horizons. These seven uncalibrated C14 ages range from 620 to 2245 ybp; the older samples were likely reworked and therefore overestimate the age of the PE. Two results (1740 and 2055 ybp) are from deposits that predate the PE. The 1740 ybp age is younger than all other constraints on the PE, but very close to two ages (1770 and 1780 ybp) from the Washoe Valley fault (Ramelli and dePolo, 1997) along the northern CRFS.

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Lawrence Livermore National Laboratory

^{14}C results

Submitter: Rood DATE: November 9, 2011

CAMS #	Sample Name	Other ID	$d^{13}C$	fraction Modern	±	$D^{14}C$	±	^{14}C age	±
154680	FL1-4	N98624	-25	0.7456	0.0027	-254.4	2.7	2360	30
154681	FL1-41	N98626	-25	0.8187	0.0031	-181.3	3.1	1605	35
154682	FL1-6	N98627	-25	0.7807	0.0028	-219.3	2.8	1990	30
154683	FL1-34	N98629	-25	0.7562	0.0028	-243.8	2.8	2245	30
154684	FL1-22	N98630	-25	0.7746	0.0027	-225.4	2.7	2050	30
154685	FL1-31	N98631	-25	0.7743	0.0027	-225.7	2.7	2055	30
154686	FL1-32	N98632	-25	0.7908	0.0028	-209.2	2.8	1885	30
154687	FL1-25	N98633	-25	0.8124	0.0028	-187.6	2.8	1670	30
154688	FL1-44	N98635	-25	0.8051	0.0028	-194.9	2.8	1740	30
154689	FL1-26	N98636	-25	0.9254	0.0032	-74.6	3.2	620	30
154690	coal	N98637	-25	0.0017	0.0001	-998.3	0.1	51330	270

1) □^{13}C values are the assumed values according to Stuiver and Polach (Radiocarbon, v. 19, p.355, 1977) when given without decimal places. Values measured for the material itself are given with a single decimal place.

2) The quoted age is in radiocarbon years using the Libby half life of 5568 years and following the conventions of Stuiver and Polach (ibid.).

3) Radiocarbon concentration is given as fraction Modern, $D^{14}C$, and conventional radiocarbon age.

4) Sample preparation backgrounds have been subtracted, based on measurements of samples of ^{14}C-free coal. Backgrounds were scaled relative to sample size.

5) All of the samples submitted in this suite have had aliquots of CO2 taken for IRMS analysis.

6) The following samples had no CO2 (poor seal):
FL1-29
FL1-38
FL1-27

7) FL1-34 had abnormally low %C relative to the other samples submitted in this suite. The sample may have had allochtonous silt associated with it.

Trench FL2

Trench FL2 (figs. 6, 10; Plate 2) was excavated across a 2 meter high scarp that crosses a narrow (~100 m wide) alluvial surface. This surface contains boulders up to a few meters in diameter. These boulders are widely scattered across most of the surface, with exception of a concentration of boulders where the drainage curves and flattens out. The fairly uniform distribution of large boulders in an otherwise sand-dominated deposit suggests deposition during a single event or sequence. We expected to find large buried boulders during trench excavation, but only two large boulders were encountered, neither of which negatively impacted the trench exposure.

Figure 10. Trench FL2 after backfilling. The scattered boulders seen in the photo were fairly representative of the surface as a whole. Photo looking south.

Trench FL2 exposed a massive, poorly sorted granitic sand deposit with minor clasts. This deposit originated from the steep southeast flank of Jobs Sister (fig. 11), and it likely resulted from slope failure that began as a boulder-dominated debris avalanche, which then became a sand-dominated flow where the slope decreased. This deposit is just one of the more recent examples of debris shedding off the unstable flank of Jobs Sister. These deposits have choked the lower part of Fay Canyon, forcing the main drainage (Luther Creek) to the south side of the canyon.

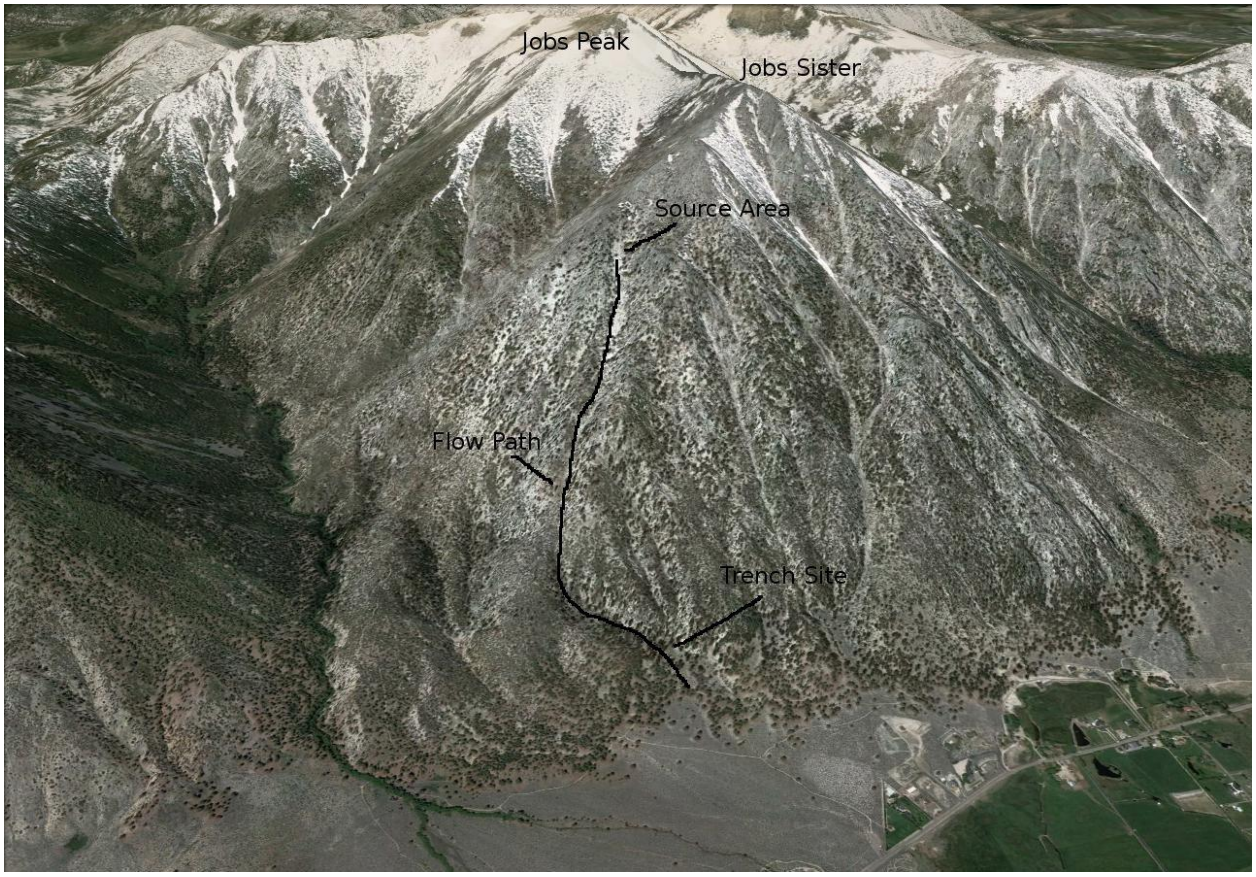

Figure 11. Image showing the source of the flow deposit in trench FL2, and how debris shed from the southeast flank of Jobs Sister has choked the lower part of Fay Canyon.

The lower part of the footwall exposure in trench FL2 consisted of thinly bedded granitic sands interpreted to be alluvial fan deposits (fig. 12). These deposits are better sorted and distinctly lighter in color than the massive overlying deposit. During trench excavation, these fan deposits were observed in the hanging wall at a similar depth, but they were buried by the time the trench was logged.

Soils in both trenches were limited to accumulation of organic material (A horizons), which is to be expected considering the forested setting and young age. No clay accumulation could be discerned, although minor clays could be masked by the dark organics.

Fault relations in trench FL2 (Plate 2) were relatively simple due to the massive deposit and singular fault trace. Colluvial wedges on the downthrown side of the fault were also relatively simple and appear to record two surface-rupturing events. The base of the penultimate-event (PE) colluvial wedge was an indistinct contact marked by a subtle color contrast. The lack of a distinctive buried soil at this horizon suggests that the PE occurred fairly shortly after deposition of the massive (flow) deposit, although the flow deposit may have created a broad, barren surface that took a while to revegetate. The upper part of the PE wedge contains a buried, organic-rich A horizon that yielded uncalibrated C14 ages ranging from 405 to 1360 ybp (Table 2), ages that provide minimums for the PE and maximums for the most recent event (MRE); the youngest age may closely approximate the age of the MRE. The PE wedge was buried by relatively clean granitic sand, which was in turn overlain by the surficial A horizon. The MRE wedge yielded C14 ages ranging from 320 to 430 ybp (Table 2).

Figure 12. Trench FL2 exposed a single, E-dipping fault trace (center of photo). Most of the trench exposed a massive sand deposit, interpreted as a flow deposit from the steep east flank of Jobs Sister. Bedded fan deposits comprise the lower part of the footwall exposure (to the right). The fan deposits were observed in the hanging wall during trench excavation, but were buried by the time of logging.

Table 2

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Lawrence Livermore National Laboratory

^{14}C results

Submitter: Rood DATE: November 9, 2011

CAMS #	Sample Name	Other ID	$\delta^{13}C$	fraction Modern	±	$D^{14}C$	±	^{14}C age	±
154618	FL2-3	N98615	-25	0.9506	0.0034	-49.4	3.4	405	30
154619	FL2-10	N98616	-25	0.9541	0.0035	-45.9	3.5	380	30
154620	FL2-12	N98617	-25	0.9478	0.0034	-52.2	3.4	430	30
154621	FL2-1	N98618	-25	0.9436	0.0039	-56.4	3.9	465	35
154622	FL2-4	N98619	-25	0.9610	0.0035	-39.0	3.5	320	30
154623	FL2-9	N98620	-25	0.8444	0.0032	-155.6	3.2	1360	35
154624	FL2-8	N98621	-25	0.5804	0.0019	-419.6	1.9	4370	30
154625	FL2-2	N98622	-25	0.4673	0.0018	-532.7	1.8	6110	35
154626	FL2-11	N98623	-25	0.9539	0.0031	-46.1	3.1	380	30
154627	coal	N98638	-25	0.0036	0.0001	-996.4	0.1	45290	190

1) $\delta^{13}C$ values are the assumed values according to Stuiver and Polach (Radiocarbon, v. 19, p.355, 1977) when given without decimal places. Values measured for the material itself are given with a single decimal place.

2) The quoted age is in radiocarbon years using the Libby half life of 5568 years and following the conventions of Stuiver and Polach (ibid.).

3) Radiocarbon concentration is given as fraction Modern, $D^{14}C$, and conventional radiocarbon age.

4) Sample preparation backgrounds have been subtracted, based on measurements of samples of ^{14}C-free coal. Backgrounds were scaled relative to sample size.

Neither of the Fay-Luther trenches exposed indicators of slip direction. However, bedrock fault surfaces near Walleys hot springs (both in a trench and adjacent gravel quarry), about 14 km to the north, show clear evidence of nearly pure dip slip (Ramelli et al., 1999).

Timing of Recent Events

A previous trench study along the main (central) part of the Genoa fault showed that the fault has ruptured with surface displacements of several meters at least twice during the late Holocene (Ramelli et al., 1999). Radiocarbon dating from this earlier study placed some constraints on the ages of the two most recent surface rupturing events. The estimated ages of these events were heavily based on the Jacks Valley trench, which exposed at least 15 distinct layers of stratified charcoal. With an approximate average of one charcoal layer per 100 years, it was inferred that an organic surface mat (likely a duff layer) regenerated and then burned over a recurrence of 50-100 years, and that such a time period was a reasonable approximation for average mean residence time (MRT).

Multiple ages of ~500 ybp from the Jacks Valley trench suggested that the most recent event occurred approximately at that time (Ramelli and others, 1999). However, subsequent trench studies along other parts of the Carson Range fault system (CRFS), including the Carson City fault (a NE-striking splay of the Genoa fault) and the highly distributed graben in the Mt. Rose fan area near Reno, yielded a handful of ages suggesting a somewhat younger event (300-400 ybp). A trench along the Washoe Valley fault did not yield good constraints on the most recent event, but did yield multiple radiocarbon ages, including one from an apparently *in situ* burn layer, that suggested two events within the past 1800 yr, again somewhat younger than the prior estimate for the Genoa fault.

Radiocarbon ages from the Fay-Luther trenches are shown below compiled with selected ages from trenches along other parts of the CRFS (Table 3). Radiocarbon ages should be considered maximums, with respect to the timing of surface rupture, because samples are subject to both inherited age and a possibility of reworking. Barring misinterpretation or other complicating factor (e.g., sample alteration), the youngest samples predating an event horizon should therefore provide the best estimate of event age.

For the youngest samples predating both the MRE and PE (Table 3), confidence in locations relative to event horizons are high. Sample FL2-3 came from a horizon buried by the MRE colluvial wedge, whereas samples CH-3 and FT-06 both came from material filling fissures created during the MRE. Sample FL1-44 came from a footwall deposit that crosscutting relations showed to be offset by two events (i.e., PE free-face retreat, followed by MRE offset). Sample DCP1-1A (from an apparently *in situ* burn layer) came from a buried surface clearly offset during two events. These samples combine to suggest the MRE occurred less than about 390 years ago, and the PE less than about 1740 years ago.

For brevity, the ages shown in this report are not calendar calibrated. However, it’s worth noting that calibration corrections for the estimated ages of the two recent events (i.e., 300 and 1700 yr) would be very small.

Table 3. Radiocarbon ages constraining the two most recent events on the CRFS. Sample ages are maximums with respect to event age, so the youngest samples predating events should provide the best estimate of event age. Sample locations include: FL1 and FL2 – Fay-Luther, southern Genoa fault; CH – C Hill, Carson City fault; DCP1 – Davis Creek Park, Washoe Valley fault; FT-06 – Mt. Rose fan, Mt. Rose fault.

FL2-4	320+/-30
FL2-10	380+/-30
FL2-11	380+/-30
FL2-12	430+/-30
FL1-26	620+/-30
------ MRE -------	
CH-3	390+/-40
FT-06	390+/-40
FL2-3	405+/-30
FL2-1	465+/-35
FL2-9	1360+/-35
FL1-41	1605+/-35
FL1-25	1670+/-30
DCP1-25A	1770+/-60
FL1-32	1885+/-30
FL1-6	1990+/-30
FL1-22	2050+/-30
FL1-31	2055+/-30
DCP1-7C	2070+/-60
FL1-34	2245+/-30
------- PE -------	
FL1-44	1740+/-30
DCP1-1A	1780+/-60
FL1-4	2360+/-30

The Fay-Luther trenches excavated for this study improved age constraints on the two most recent events on the Genoa fault, and we can conclude with reasonable confidence that ruptures extended along the southern Genoa fault. Combined with results from other parts of the CRFS, indicate most, if not all, of the CRFS ruptured less than 400 years ago and less than 1800 years ago. It seems increasingly likely that the Jacks Valley ages are subject to an MRT of at least 200 yr and that prior estimates of event age were slightly too old.

The timing of events along different parts of the CRFS are close enough that ruptures are clearly related, but we don't have the resolution to say whether the entire fault system ruptured during a single event – a 100-km-long rupture would be unusual for a normal fault – or as a sequence of triggered events, similar to the Fairview Peak/Dixie Valley sequence of 1954.

References

Armin, R.A., and John, D.A., 1983, Geologic map of the Freel Peak 15-minute quadrangle, California and Nevada, with Quaternary geology by J.C. Dohrenwend: U.S. Geological Survey, Miscellaneous Investigations Map I-1424, scale 1:62,500.

Clark, M.M., Harms, K.H., Lienkaemper, J.J., Harwood, D.S., Lajoie, K.R., Matti, J.C., Perkins, J.A., Rymer, M.J, Sarna-Wojcicki, A.M., Sharp, R.V., Sims, J.D., Tinsley III, J.C., and Ziony, J.I., 1984, Preliminary slip-rate table and map of late Quaternary faults of California: U.S. Geological Survey, Open-file Report 84-106.

Lawson, A.C., 1912, The recent fault scarps at Genoa, Nevada: Bulletin Seismological Society of America, v. 2, p. 193-200.

Pease, R.C., 1980, Geologic map of the Genoa 7.5-minute quadrangle, Nevada Bureau of Mines and Geology Map 1Cg, scale 1:24,000.

Ramelli, A.R., Bell, J.W., dePolo, C.M., and Yount, J.C., 1999, Large-magnitude, Late Holocene Earthquakes on the Genoa Fault, West-Central Nevada and Eastern California: Bulletin Seismological Society of America, v. 89, no. 6, p. 1458-1472.

Ramelli, A.R., and dePolo, C.M., 1997, Trenching and related studies of the northern Sierra Nevada range-front fault system: U.S. Geological Survey, NEHRP final technical report, award 1434-95-G-2606.

Rood, D. H., Harvey, J.E., Ramelli, A.R., Burbank, D.W., Bookhagen, B., 2011, Temporal fault slip rate and rupture patterns on the Genoa fault, central Eastern Sierra Nevada, integrating ground-based LiDAR, 10Be surface exposure dating, and paleoseismology: American Geophysical Union, Fall Meeting 2011, abstract #T43I-07.

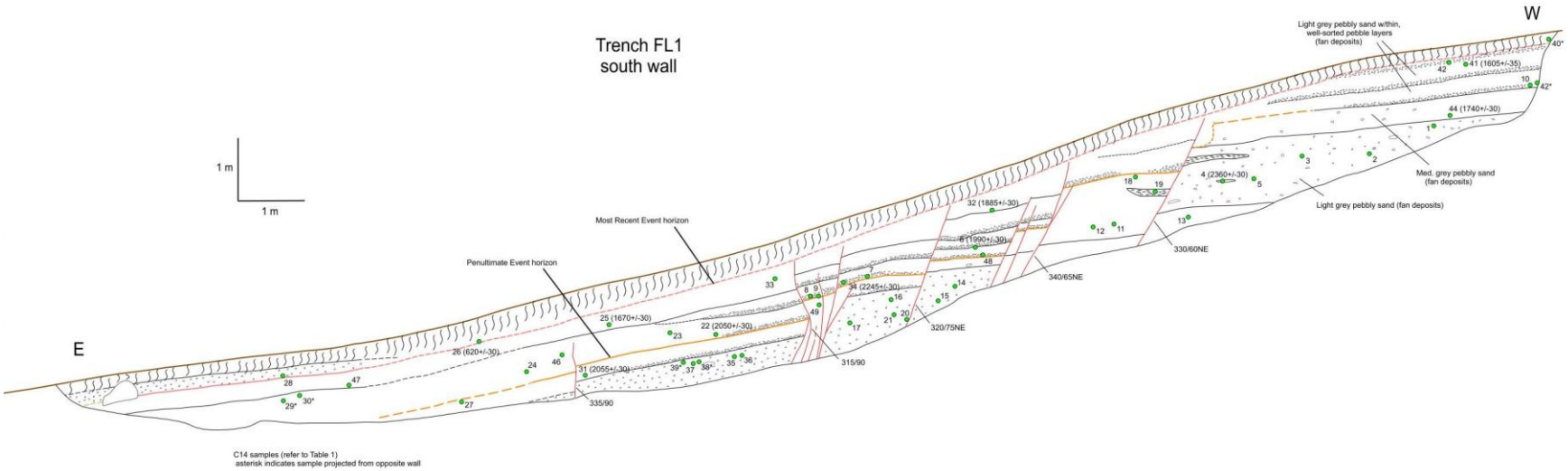
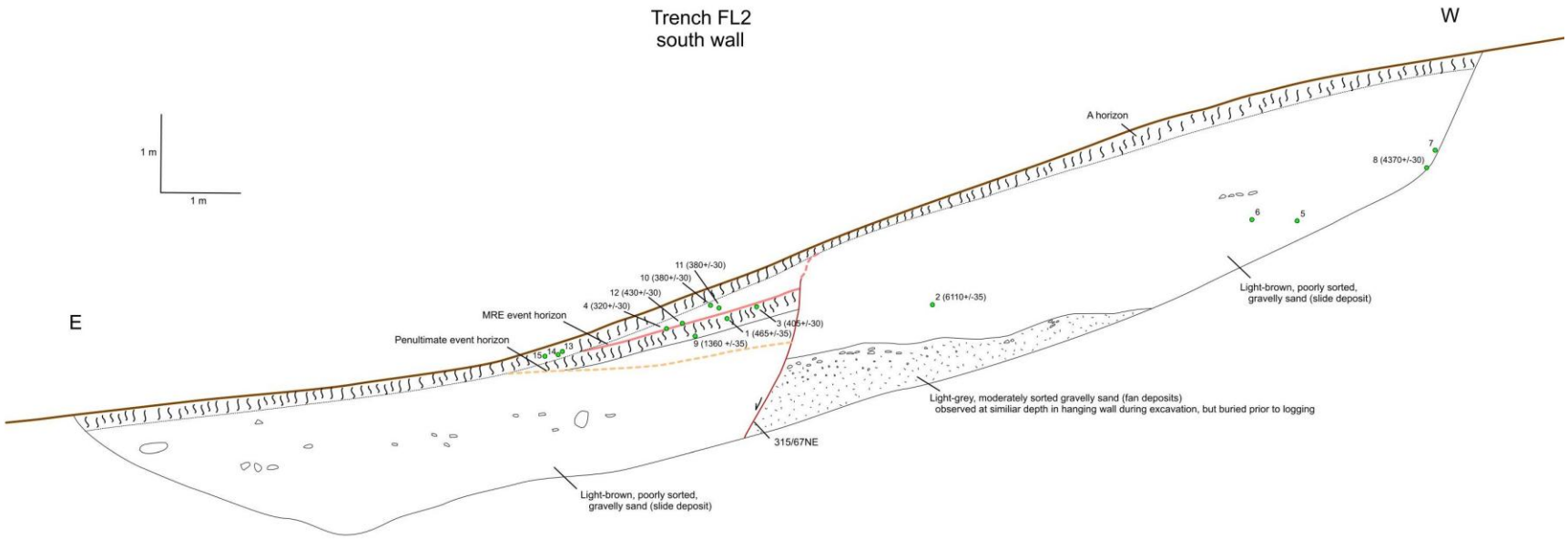

Trench FL1
south wall
W
E
1 m
1 m
Light grey pebbly sand w/thin, well-sorted pebble layers (fan deposits)
Med. grey pebbly sand (fan deposits)
Light grey pebbly sand (fan deposits)
Most Recent Event horizon
Penultimate Event horizon
40*
41 (1605+/-35)
42
10
42*
44 (1740+/-30)
1
3
2
4 (2360+/-30)
5
18
19
32 (1885+/-30)
6 (1990+/-30)
48
12
11
13
330/60NE
340/65NE
33
7
8
9
34 (2245+/-30)
16
15
14
49
17
21
20
320/75NE
315/90
25 (1670+/-30)
23
22 (2050+/-30)
26 (620+/-30)
24
46
31 (2055+/-30)
39*
37
38*
35
36
28
47
29*
30*
27
335/90
C14 samples (refer to Table 1)
asterisk indicates sample projected from opposite wall

Plate 2


Trench FL2
south wall
W
E
1 m
1 m
A horizon
7
8 (4370+/-30)
6
5
11 (380+/-30)
10 (380+/-30)
12 (430+/-30)
4 (320+/-30)
MRE event horizon
Penultimate event horizon
15
14
13
3 (405+/-30)
1 (465+/-35)
9 (1360 +/-35)
2 (6110+/-35)
Light-brown, poorly sorted,
gravelly sand (slide deposit)
Light-grey, moderately sorted gravelly sand (fan deposits)
observed at similiar depth in hanging wall during excavation, but buried prior to logging
315/67NE
Light-brown, poorly sorted,
gravelly sand (slide deposit)