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Paleoseismic Studies along the Eastern Carson Valley fault system

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ABSTRACT

The Eastern Carson Valley fault system (ECVFS) is a widespread system with over 200 fault traces in an area approximately 10 km by 25 km. Within the ECVFS fault traces are generally short, 1 to 2 km long, are subparallel and anastomosing, and have normal dip-slip, and right-lateral strike-slip components. Late Holocene surface ruptures can be mapped in the ECVFS because of their freshness in expression. These ruptures occur in parallel and left, en echelon patterns and involved many faults, and have scarps as much as 1 m high. The ruptures extend over a total distance of 18 km as one or two zones (two separate zones would have minimum distances of 9 and 11 km). The faults of the ECVFS are expressed as single-event fault scarps, multiple-event compound fault scarps, escarpments, oversteepened hillslope bases, graben, and secondary features such as deflected drainages, aligned drainages, and vegetation, tonal, and topographic lineaments. Small ridges and other landscape features are better developed and expressed in the eastern half of the ECVFS. In the western half of the system, late Quaternary alluvium partly covers the landscape leading to more muted expression, although faults are not less active than in the eastern part. Several trenches were excavated to expose evidence for paleoearthquakes. A young age for the eastern part of the mapped surface ruptures, between 520 and 921 years before present, was confirmed by trenching. Other Holocene and latest Pleistocene events were discovered, but further dating is needed to determine their ages (some dates are pending). Evidence for at least three paleoearthquakes, and as many as four to seven paleoearthquakes, was found in trenching studies. Well developed colluvial wedge deposits were exposed, that were as much as 1.4 m thick near the fault; these thicknesses can be associated with fault scarps that were 1.5 to 3 m high. Important seismic hazard characteristics of the ECVFS include the distributed nature of surface ruptures, end-to-end lengths of as much as 25 km, and apparent vertical offsets between 1 and 3 m, with similar amounts of right-lateral offset possible. Considering a minimum threshold value for surface faulting, these parameters can be associated with earthquakes of M6.3 to M7+. Earthquake recurrence cannot be confidently assessed at this time, but multiple Holocene earthquakes have occurred. The numerous fault traces involved with the ECVFS pose an unusually large surface-rupture hazard, which should be avoided by encroaching development.

INTRODUCTION

The Eastern Carson Valley fault system (ECVFS) is a major earthquake source that has not been previously characterized by detailed studies, but lies within the second largest urban region in Nevada, the Reno-Carson City urban corridor. The north-striking system is unusual because of its highly distributed nature of over 200 Quaternary fault traces in a zone up to 10-km wide. Although individual fault traces are generally short, commonly 1 to 2 km long, the most-recent surface rupture(s?) involved numerous fault traces that form a left-stepping *en echelon* pattern which obliquely crosses the ECVFS, based on recent geologic mapping and trench studies. The overall surface-rupture length was greater than 9 km and vertical offsets, measured at several sites along the rupture, range from 0.3 to 1 m. Given that multiple fault strands have ruptured during paleoearthquakes, many with sizeable displacements, the ECVFS poses significant earthquake-shaking and unusually significant ground-rupture hazards.

This study investigated the earthquake history, rupture pattern, size of coseismic displacements, overall sense of faulting, and slip rates on the ECVFS. These results are then used as a basis for characterizing the seismic-hazard potential of the fault system. A detailed characterization of the ECVFS is important for understanding regional earthquake hazards, especially in probabilistic seismic hazard studies, because of its rate of activity and proximity to the urban corridor where data completeness is an issue.

Carson Valley is bounded on the east by the Pine Nut Mountains, and on the west by the Carson Range. Although the structural margin of the western side of the valley is abrupt with down-dropping of the basin occurring along the Genoa fault (Ramelli and others, 1999), the eastern side of the valley is a gradual rise in bedrock to the Pine Nut Mountains that occurs over a series of small faults (Maurer, 1984). The ECVFS crosses the eastern half of Carson Valley, and offsets and tilts latest Pliocene (<3 Ma) and Quaternary alluvial and lacustrine deposits (dePolo and others, 2000). Displacement along these faults has created a series of small hills and uplifted alluvial terraces and fan remnants.

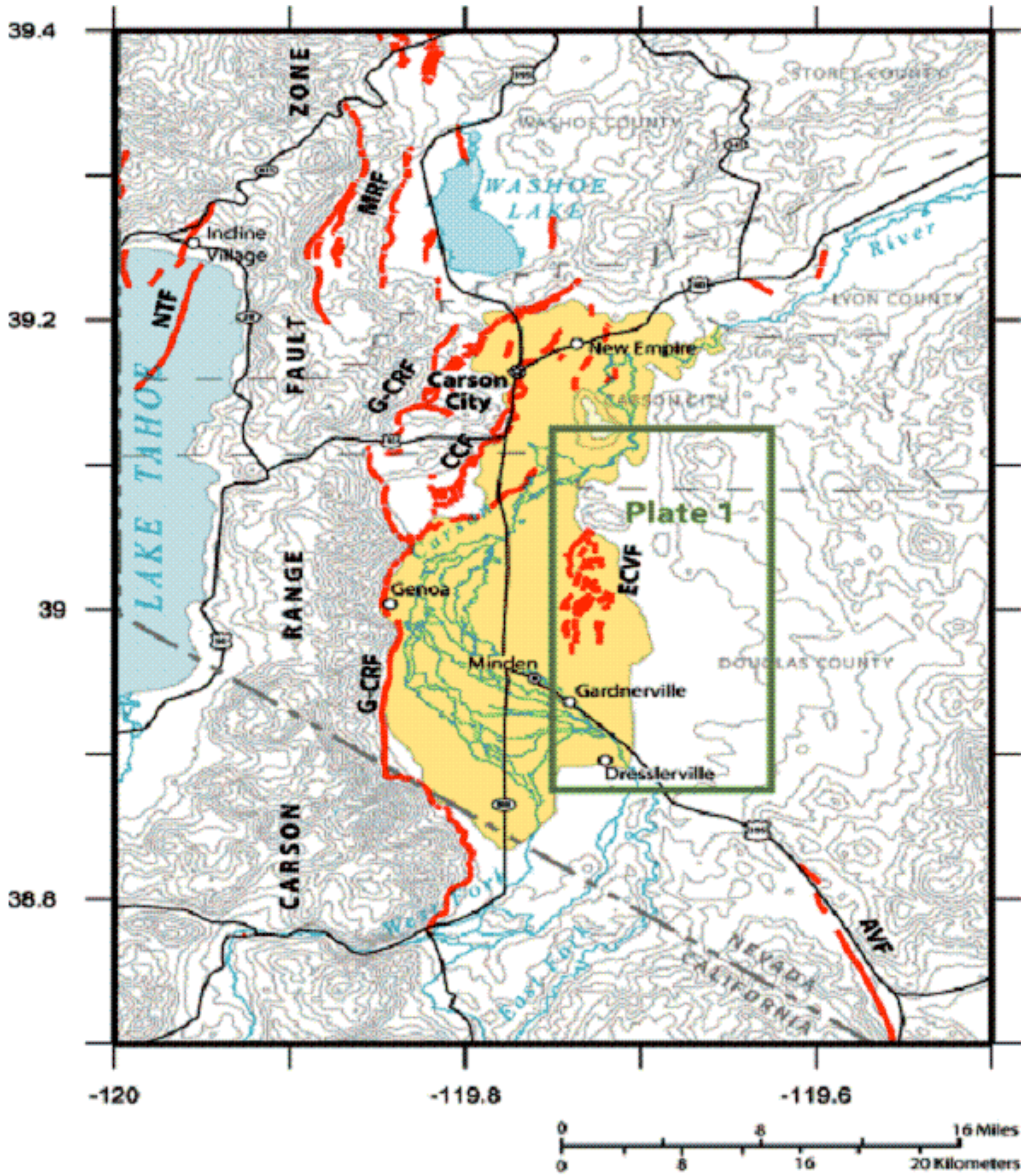
The Reno-Carson City urban corridor is the second most populated area in Nevada, with about 500,000 people, and the potential for more than 200,000 visitors during special events. The corridor is rapidly growing with major construction and expansion occurring in Carson Valley. Most of these people live in the valleys underlain by low shear-wave velocity sediments and basin configurations that likely amplify earthquake ground motion. The ECVFS traverses much of eastern Carson Valley, where development is progressing very rapidly with hundreds of homes in subdivisions and “gentleman ranches.” Consequently, many possible trenching locations along the fault system have been modified or their paleoseismic record lost due to urbanization.

EASTERN CARSON VALLEY FAULT SYSTEM

The highly distributed Eastern Carson Valley fault system (ECVFS) is a prominent system of faults extending along the entire length of eastern Carson Valley, about 21 to 26 km (fig. 1; Plate 1). The 8- to 10-km wide system, a third of the width of the valley, extends from the foothills of the Pine Nut Mountains westward to near Highway 395, where it's buried by young alluvium. The ECVFS extends northward from near the intersection of the northwest-striking, right-lateral Double Spring Flat fault zone and the northeast-striking, left-lateral Mud Lake fault zone, through eastern Carson Valley. Faults of the ECVFS, although apparently fewer in number, continue northward and merge with the northeast-striking Carson lineament fault zone and/or end north of Carson City, near a Quaternary volcanic center. Other faults with structural connections to the ECVFS are to the east in the foothills of the Pine Nut Mountains, and possibly to the west buried by young alluvium, but these were not mapped and are poorly defined.

The fault system has been recently mapped by Garside and Rigby (1999), and dePolo and others (2000) at a scale of 1:24,000. Although there are still likely buried faults and faults in Pliocene sediments that lack overlying Quaternary deposits and are more difficult to detect, we believe we have identified the major fault traces in the system. Plate 1 is a Quaternary fault map of the ECVFS with the geomorphic expression of faults annotated. The plate was compiled using dePolo and others (2000) and Garside and Rigby (1998) as a base fault map and modifying and adding fault traces. Geomorphic feature were identified on color 1:24,000 photos and low-sun-angle black and white 1:12,000 photos, and through field observations. Fault traces identified on photographs were transferred to topographic maps using a PG-2 plotter. A 1:24,000 map of the ECVFS (Plate 1) was compiled from geologic maps, and modified based on photogeologic interpretations, field investigations, and trenching studies. The geomorphic expression of fault traces has been annotated on the map with abbreviations. The map illustrates the surface-rupture potential of the ECVFS, and provides as a guide for urban planning and a means of avoiding placing occupied structures on active fault traces.

Aseismic surface cracking has occurred along the ECVFS on two or three separate occasions. The Fish Spring Flat fault zone first cracked aseismically in the summer of 1988 over a section about 1 km long (Bell and Helm, 1998). John Bell of the Nevada Bureau of Mines and Geology excavated a trench across the fault zone to explore the nature of the crack, and discovered it could be directly related to minor movement on the fault. This and subsequent trenches along this fault zone have exposed evidence for prior ground cracking and for discrete event deposits, which may be important in discriminate the earthquake record from the creep record. Preliminary observations from Bell's trench indicate most (if not all) of the offset in the late Quaternary offsets occurred during paleoearthquakes, rather than by creep. A second crack in the same location was created by the 1994 Double Spring Flat earthquake (M5.8) (Ramelli and others, 2003); this earthquake was 15 km to the south and the cracking is considered to be sympathetic or triggered in nature (Ramelli and others, 2003). A third episode may have occurred during the summer or fall of 2004. A small fracture was created under a reservoir about 3 km NNW of the earlier cracks. Trenching indicated this crack was not along a major fault, and carbonate filled fractures were also seen in the trench indicating earlier, prehistorical episodes of cracking.



7.5' QUADRANGLES

1. Carson City
2. New Empire
3. Genoa
4. McTarnahan Hill
5. Minden
6. Gardnerville

LATEST QUATERNARY FAULT

MRF	Mount Rose
NTF	Northern Tahoe
G-CRF	Genoa-Carson Range
CCF	Carson City
ECVF	East Carson Valley
AVF	Antelope Valley

Figure 1. Location of East Carson Valley fault system

Figure 1. Location of East Carson Valley fault system

STRUCTURE

The ECVFS is a complex zone of subparallel, nested and generally east-dipping faults which contains over 200 probable Quaternary fault traces, commonly 1 to 2 km long but some are as much as 4 km long (dePolo and others, 2000). The faults define gently west-tilted blocks and half graben, and to a lesser extent nested graben. Although there are several antithetic, west-dipping faults which in some cases bound graben with accumulations of alluvium. Cross-strike distances between fault traces are small, typically 20 to 300 m. This pattern of faulting appears likely to have been inherited from a Miocene extensional episode that affected the subsurface bedrock similarly to what has been documented in the Singatse Range and Yerington District to the east (Proffett, 1977). In the Singatse Range several shingled, east-dipping faults occur in a similar, subparallel arrangement.

The total vertical displacement across individual faults ranges from as little as a meter to over 100 m, but commonly is a few meters to tens of meters. However, the overall modest relief and continuity of Tertiary strata across the zone (dePolo and others, 2000), as well as the absence of a prominent gravity gradient (Maurer, 1984), indicate a lack of significant cumulative vertical displacement across the fault system. In addition to the more obvious evidence for normal dip-slip displacement, strike-slip faulting also appears to be potentially important along the ECVFS. Strike-slip faulting is likely because of local earthquake focal mechanisms (Ichinose and others, 1998), oblique slickensides (Bell and Ramelli, 2000, pers. comm.), left-stepping fault patterns at map and trench scales (discussed below), and structural connectivity to the Double Spring Flat fault to the south, which appears to have a large strike-slip component (Ichinose and others, 1998). Documentation of a strike-slip component along the ECVFS is important because the system looks like a group of subparallel, normal dip-slip faults, not a typical strike-slip fault. If strike-slip motion can be documented, then the “clues” of the lateral component from the system (for example, left-stepping pattern in the main fault traces within the system) may be used to identify other systems in the western Great Basin that might have lateral components as well.

The most recent surface rupture(s) is expressed by distinct scarps or ‘oversteepened’ faces on compound scarps, 1 m high or less, that delineate a northwest zone of left-stepping *en echelon* faults (Plate 1). The small oversteepened part of the fault scarps is very striking when shadowed by the sun as it grazes the scarp face. Geologic mapping reveals two general areas of distributed recent surface ruptures. The eastern set includes the Fish Spring Flat fault zone and appears to cross the ECVFS with a 4-km cross-strike distance. The western zone overlaps the eastern zone but the two are separated by a 1 km-wide gap where no very recent scarps have been mapped. The separation between the two rupture groups may indicate that they are related to separate events. This paleoseismic study of the ECVFS we will attempt to test this hypothesis with a trenching investigation. Faults in both paleoearthquake rupture groups were trenched and a record of late Quaternary earthquakes were documented.

TECTONIC GEOMORPHOLOGY

The geomorphic expression of the ECVFS, which dominantly reflects the normal dip-slip components on the faults, includes fault scarps, compound scarps and escarpments, oversteepened hillslope bases, and secondary effects such as stream deflections, captured drainages, and ponded alluvium.

Paleoearthquakes are also commonly expressed has small fault scarps, steep faces on compound scarps, and side-hill fault scarps. Other common expressions of the ECVFS are vegetation, topographic, and tonal lineaments, aligned drainages, closed depressions, and graben.

Geomorphic features are commonly more pronounced, more continuous, and higher in the eastern half of the ECVFS than in the western half. This is probably because the western half of the system is being eroded and buried by young alluvium from the Pine Nut Mountains. Whereas drainages are generally entrenched in the eastern half of the system, they form young alluvial fans over the western half. Consequently the surficial geology is younger in the western half than in the eastern half, surficial deposits are offset less by faults, and the geomorphic expression is less pronounced.

There are at least five categories of tectonogeomorphic features within the fault system, including: 1) large scale features (e.g., uplifted areas and flats that are $1 km in size); 2) small elongate ridges uplifted and usually bound by individual faults; 3) multiple-event scarps and fault escarpments; 4) single-event scarps; and 5) other features indicative of Quaternary faulting (e.g., lineaments, closed depressions, etc.).

The distinct elongate ridges result from 10 m to 200 m vertical offsets along bounding faults. These apparent tilt-blocks are commonly limited in length to about 1 km, or the length of the bounding fault. The ridges are commonly cored by Plio-Pleistocene sediment and are overlain by Quaternary alluvial gravels that have been uplifted and isolated from the piedmont. The faulted sides of these ridges have oversteepened portions near their mid-slopes or the lower parts of the hill-slope. Some faults along the ridges have small ($1 m high) fault scarps within the oversteepened portions.

Smaller hills in younger alluvium and insert terraces commonly are fronted by a compound fault scarps. These uplifted features likely formed since middle to late Pleistocene based on soil development. The oversteepened bases along some ridges are also likely of a similar age and in a few cases are continuous with adjacent compound fault scarps demonstrating the relationship. In the area of Trenches 1-3 there are several uplifted, inset fluvial terraces on the eastern side of the fault; in Buckeye Creek there are several levels of terraces, some of which were likely isolated during tectonic events.

PALEOSEISMIC INVESTIGATIONS

Two types of paleoseismic investigations were conducted along the ECVFS: 1) mapping of young ruptures from stereoscopic examination of aerial photography, and 2) exploratory trenching and dating. The mapping of young ruptures is a preliminary effort, mostly based on photographic interpretation and limited field investigations. The exploratory trenching was the dominant field effort and exposed evidence for the young paleoearthquake that created the distinct surface ruptures, and several earlier paleoevents.

Young Surface Ruptures

Young surface ruptures associated with the most recent event(s) are shown in a preliminary manner on Plate 1 (yellow highlighted faults). The ruptures, which are delineated by low scarps, side-hill scarps, uplifted and dissected stream terraces, and vegetation lineaments, are easily recognized on low-sun-angle photography taken in the 1970's by Dr. Slemmons, University of Nevada, Reno. The ruptures, although likely incomplete in number and extent, seem to provide clues to earthquakes rupture behavior along the system. The most recent event occurred between 520 and 921 cal B.P., based on bracketing radiocarbon dates from the paleoseismic trenches.

Trenching Investigations

Our approach to deciphering the paleoearthquake history of the ECVFS was to document the paleoseismic record at several sites, in each of the two groups of young surface ruptures, and then to compare the various paleoearthquake records. The history of these ruptures will also be compared to that of the Carson Range fault zone (Ramelli et al., 1999), in an effort to verify that the two are independent earthquake sources, rather than rupturing coseismically. Radiocarbon samples have been collected and provided important preliminary age constraints, but other samples have been archived due to limited funds; we are pursuing obtaining additional funding to complete this analysis. Thus, several trenches were excavated, cleaned, photographed, described, accurately surveyed, and logged for this research study. Within days after closing three of the trenches, the sites were graded or deeply plowed, demonstrating the timeliness of the study. Radiocarbon dates collected to date are given in Table 1.

Table 1 Radiocarbon Dates from Trenching Studies along the ECVFS

Sample #	Lab #	del 13C, %o	14C date, ybp	Dendrocorrected Date, cal. B.P.
T2-RC3	GX31287	-24.2	650+/-80	520 – 726 (2 sigma)
T2-RC4	GX31289	-24.3	870+/-70	678 – 921 (2 sigma)

Trench 1-3 Complex

Trenches 1-3 were closely spaced along one of the largest faults in the system, the Fish Springs Flat fault zone, which is marked by compound scarps with distinct breaks in slope and by single-event scarps crossing the youngest inset terraces and alluvial fans (fig. 2). The trenches were excavated into three different terrace remnants that have been uplifted and isolated form stream erosion or deposition by offset along the same fault. The fault strikes N2 E through the trench sites and is well expressed by the young paleoseismic rupture (Plate 1). The trenches exposed evidence for the most recent event (MRE) and for several prior paleoearthquakes. The most recent rupture offset the lowest terrace at Trench 1, is about mid-slope on the compound scarp at Trench 2, and is about 2 to 3 m above the base of the slope on the large, compound scarp at Trench 3.

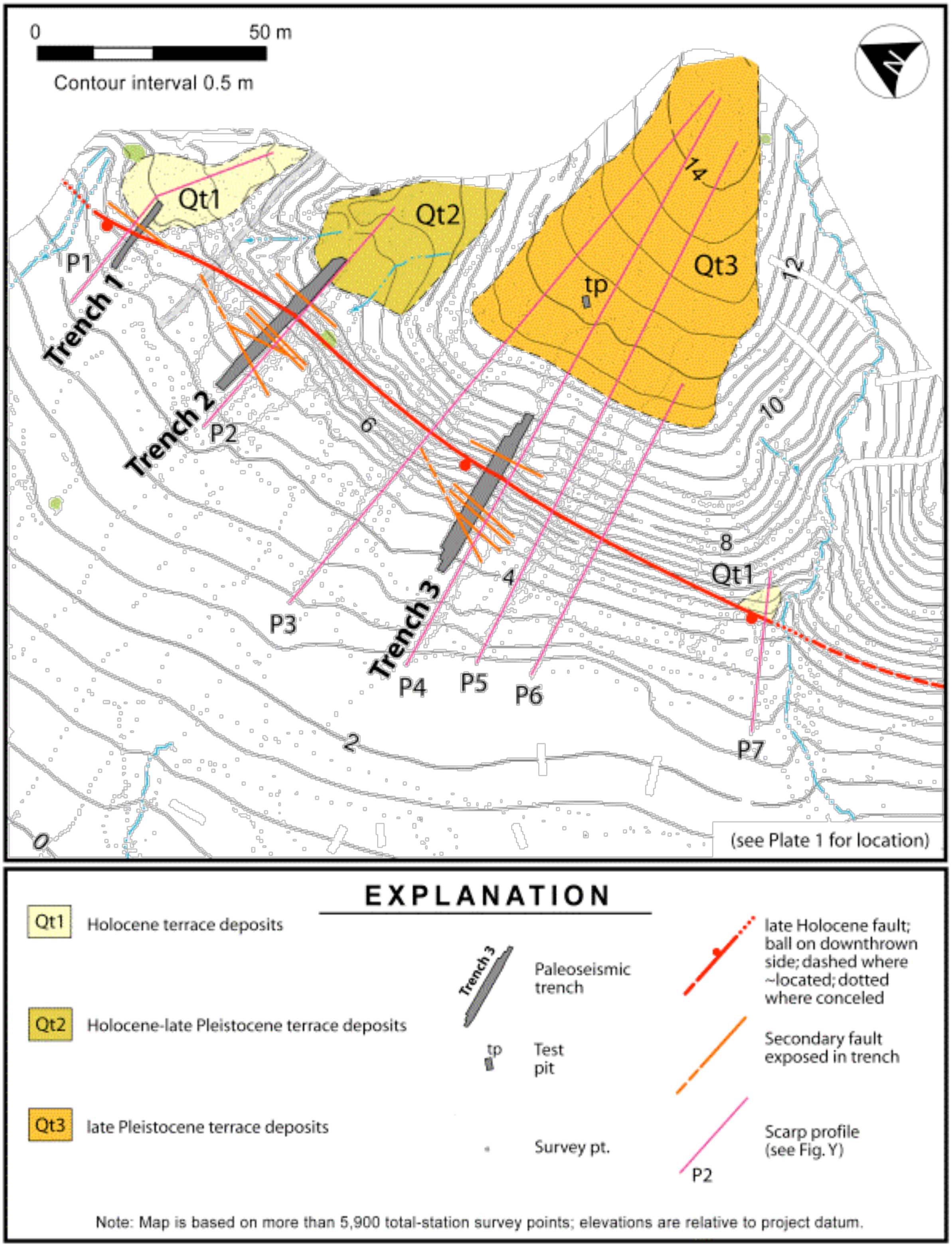


Figure 2. Topographic map showing selected late Quaternary terraces in the vicinity of East Carson Valley fault system trenches 1, 2 and 3.

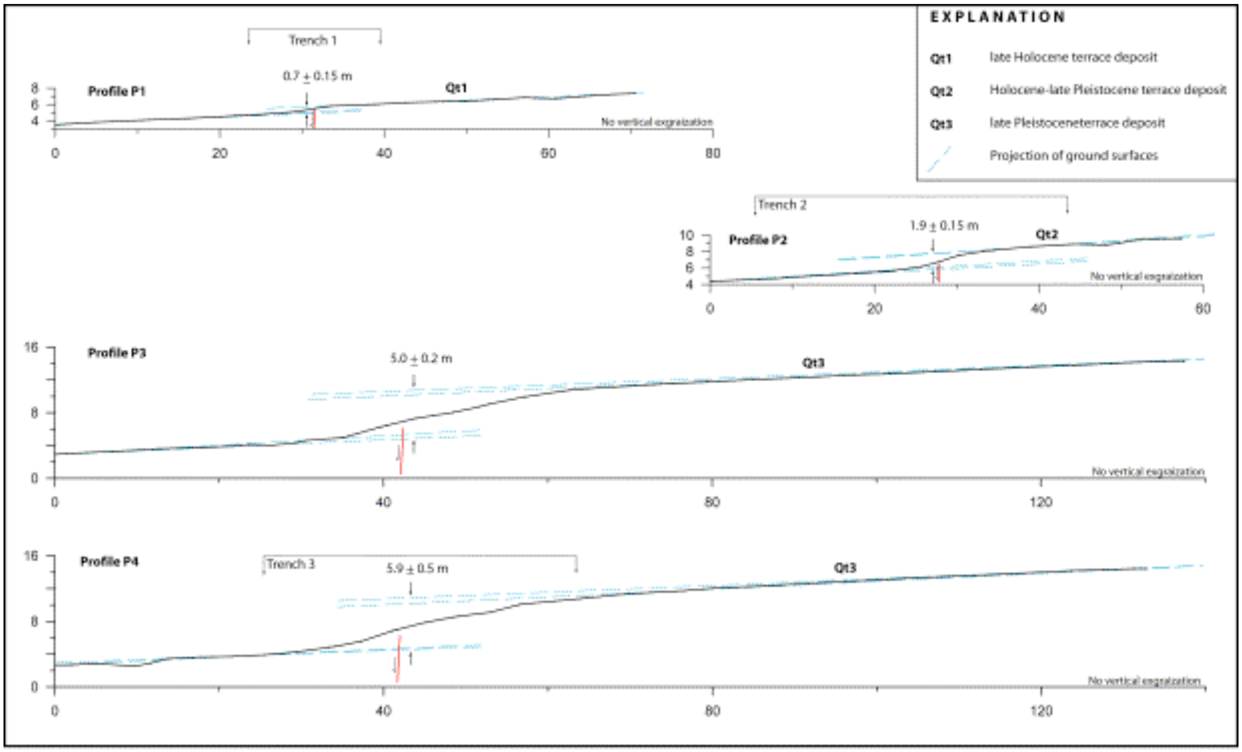


Figure 3. Scarp profiles, based on total station survey, showing estimated surface separation.

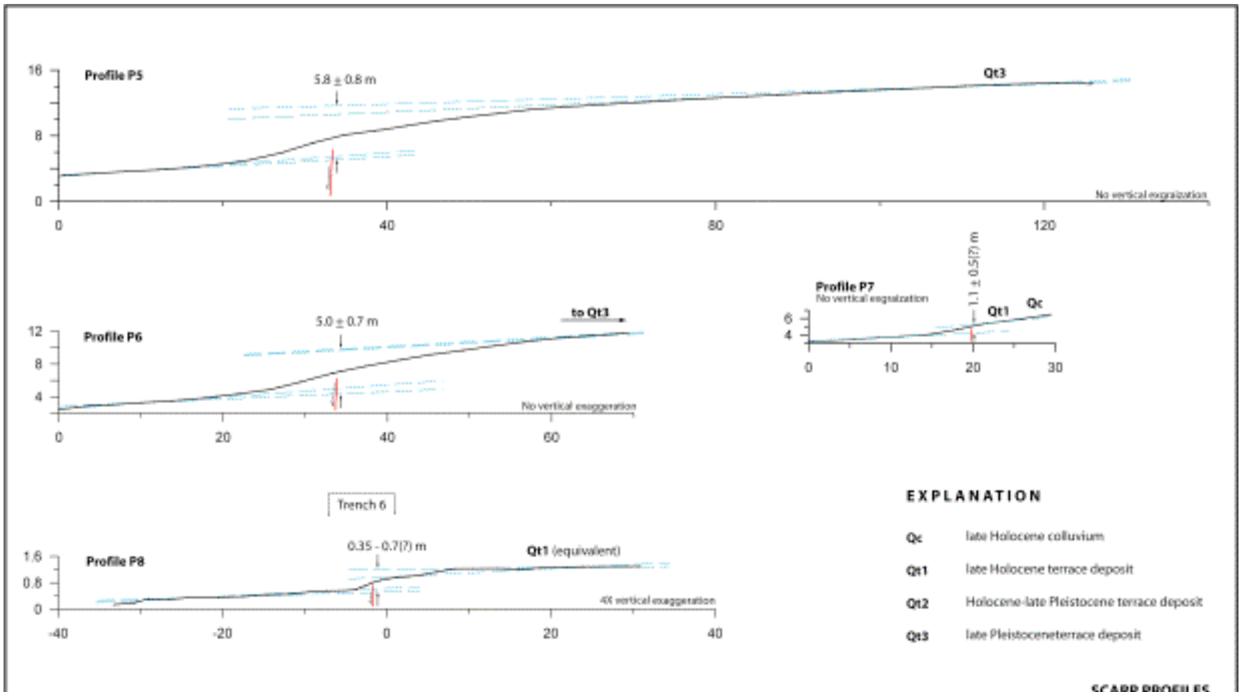


Figure 3. (continued).

Trench 1 was sited to document the most recent event and was excavated across a single-event scarp on the youngest of the three terraces. The height of the terrace above the active channel, about 0.5 m, is comparable to the amount of offset during the MRE, suggesting that the terrace was formed in response to the event. This inference is supported by the weak soil developed in the terrace deposits and by the recent age constraints for the earthquake (discussed below). Trench 2 was excavated across the same fault, but about 30 m to the south in the middle terrace remnant. This trench targeted the latest Quaternary activity on the fault. The middle terrace is about 1.5 to 2 m above the active stream channel and was uplifted during three late Quaternary earthquakes (discussed below). Trench 3 was excavated across the fault where it is expressed as a large compound scarp on a late Quaternary terrace, about 4 to 5 m above the active drainage. This trench was designed to examine the longest possible paleoseismic history at the site. All trenches were located where it was deemed preservation of sediment on the scarp face was the best, avoiding small drainages off the hillslope.

<u>Trench 1</u>

Trench 1 was located across the lowest terrace uplifted along the Fish Springs fault. The local strike of the single-event fault scarp at the trench is N5 E. The trench was oriented N75 W and was 16 m long. A handheld-GPS location of the reference point for the trench is 38 59.375' N., 119 38.970' W.. The trench exposed a sequence of terrace gravelly sands that are offset across a zone of faults, which is about 30 to 40 cm wide. Four Holocene units were mapped, three are pre-MRE and a young post-MRE unit on the relatively downthrown side of the fault. The location of Trench 1 is shown on Plate 1 and a detailed log of the south wall is shown in Plate 2.

<u>Stratigraphy</u>: A sequence of four Holocene fluvial, alluvial, and eolian deposits were exposed throughout Trench 1. The oldest, Unit 4, is a whitish sand with a distinct, abrupt upper contact. The unit is composed of massive coarse to medium sand with gravelly lenses. The whitish color results from carbonate as indicated by strong effervesces with HCl. Although the matrix has carbonate, it is a light, loose powdery constituent, and may be partly formed by groundwater processes. The poorly sorted, gravelly medium to coarse sand of Unit 3 overlies Unit 4. Unit 3 has several cobbly and pebbly lenses east of the fault, and some iron staining on gravel clasts. Unit 3 seems to taper in thickness from 100 cm thick east of the fault, to 60 cm thick west of the fault. Alternatively Unit 2b might be part of Unit 3 making Unit 3's thickness west of the fault 90 cm, but this is not the preferred interpretation. Unit 3 has a slightly different character across the fault, possibly due to lateral juxtaposition. Unit 2 is a massive silty fine sand with minor gravel in the middle and lower portions. The unit is composed of fluvial-channel and overbank deposits with some cross laminations. In the western part of the trench a weak vesicular A horizon (Unit 2a) makes up the top of Unit 2; this Av is formed in materials apparently eroded from the scarp on the eastern side of the fault. Units 2 through 4 are all faulted by the MRE, whereas, Unit 1 was deposited after the event, and a small colluvial wedge, Unit 1a, was deposited in response to the MRE. The as much as 20 cm-thick wedge is made well sorted fine sand with a several gravel clasts, colluvium derived from the low scarp and alluvium from a small cone deposited by a small drainage located immediately south of the trench.

<u>Structure</u>: The fault is made up of many near-vertical fault traces forming a 2.3 m-wide zone, that can be divided into a distributed eastern zone of fractures and an intense 30- to 50-cm-wide western zone of

faults, where most of the displacement occurred during the MRE. The western zone is strongly sheared and remarkably vertical with numerous small faults. Fault F1d cut through units 1 and 2, but was subsequently truncated during erosion of the MRE freeface. Thus, the contact between the colluvial wedge (Unit 1a) and Unit 2 is a vertical buttress unconformity (Plate 2). The terrace sequence exposed in Trench 1 (Units 2-4) has apparent been vertically offset 82 to 90 cm across the fault zone, likely with an unknown amount of lateral displacement. The vertical offset is consistent with the about 80 cm-high scarp on the low terrace.

The faults all strike N10 E, indicating that they likely have a left-stepping relationship to the main fault. Thus the faults might represent sheared Reidel-style fractures, consistent with right lateral displacement.

A wedge of sediment between faults F1b and F1c maybe laterally transported or wrenched into the plane of the trench wall as an explanation of the abrupt change in thickness of Unit 4 across fault F1b.

Paleoearthquake History: The paleoearthquake history of Trench 1 is simple, only the MRE is evidenced. The event produced an apparent vertical offset of 82 to 90 cm, and a right lateral offset of possibly a similar amount. The lateral amount is inferred form the strike-slip character of the fault, but is limited by the similarities of the units on either side of the fault.

Trench 2

Trench 2 was excavated across a 2 m-high compound fault scarp striking N15 E across the site (fig. 2). Here a sequence of four(?) paleoearthquakes has uplifted and isolated the middle terrace. The total offset history of the terrace was anticipated to be encountered in Trench 2, because of the potential to expose correlative deposits on both sides of the fault. The trench was 38 m long, up to 3 m deep, and was oriented N73 W. The location of Trench 2 is shown in Plate 1 (GPS location 38 59.358' N., 119 38.977' W) and the log of the trench is shown in Plate 3.

Stratigraphy: Trench 2 exposed a 3 m-thick stack of colluvial, hyperconcentrated alluvial, and fluvial deposits that on the footwall bury a Plio-Pleistocene alluvial sequence (Plate 2). The alluvial and fluvial deposits are primarily related to deposition of the middle or intermediate-aged terrace, which was subsequently truncated by down-west vertical movement on the fault. The colluvial deposits are derived from degradation of the associated fault scarp.

The oldest deposits in Trench 2 are gray, Plio-Pleistocene deposits that underlie the Quaternary alluvium on the footwall. These deposits are thinly bedded to massive sands and silty sands that have some fluvial structure, including cross laminations. With exception of a few faults, and a distributed fracture zone near the main fault, the sediment is relatively undisturbed.

The oldest late Quaternary deposits in the trench are Units 7 through 5. These deposits make up the lower meter of the trench in the hanging wall, and are slightly tilted to the east, east of fault F11 (Plate 2). Unit 7 is a massive gravelly, medium to fine sandy colluvial deposit, with local alluvial and eolian facies. Unit 6 is a colluvial deposit that grades westward into an alluvial deposit, Unit 6a, which is a cobbly, sandy, gravelly deposit. Both Units 6 and 7 have a gray color that indicates the inclusion of a significant component of Tertiary sediments from the footwall. Unit 5 is a fluvial deposit composed of sandy gravel and gravelly sand, which may represent the upper-most Terrace 2 deposits, prior to fault activity.

Units 4 through 1 are dominated by poorly sorted, matrix-supported colluvial deposits derived from the scarp on the middle terrace deposits. Unit 4 contains a gravelly, clayey fine to very fine sandy colluvial package that overlies the more alluvial parts (Units 4a and 4b) of the unit. This deposit was likely deposited in response to an earthquake, but it lacks a clear proximal colluvial-wedge facies. However, if fine-grained Plio-Pleistocene sediment were exposed in the free face, the scarp may have been limited in coarse materials needed to develop proximal wedge facies. Units 4a and 4b are clayey, medium and fine sandy gravel and clayey, coarse sandy gravel, respectively. They are massive to stratified, clast and matrix supported gravel deposits.

Unit 3a and 3b are distinct parts of a colluvial wedge deposit. Unit 3b is a relatively coarse, cobbly, gravelly, clayey coarse to very fine sand. It appears to be a rapidly deposited hyperconcentrated alluvium that filled a depression along the base of the growing scarp[1]. Unit 3a is a gravelly, clayey, fine and very fine sandy colluvial deposit with an eolian input near the top. A bulk radiocarbon sample of Unit 3a yielded a dendro-calibrated age ranging from 3,372 to 4,179 cal BP (sample T2-RC1 in Table1).

Unit 2 grades westward from coarse colluvium to alluvium, which further grades to the alluvial fan overlying the middle terrace deposits on the downthrown side of the fault. Unit 2b is a colluvial deposit composed of poorly sorted, matrix supported, gravelly, clayey fine sandy. Unit 2b has a well developed proximal colluvial-wedge facies and basal colluvial stoneline. This unit grades into a well developed, polygenetic Bt horizon exposed to the east. Unit 2a has a large eolian input forming a discontinuous Av horizon. This deposit represents the “stable” surface formed on Unit 2b colluvium. A bulk radiocarbon sample of the best exposure of the Unit 2a Av soil, which was on the north wall, yielded a radiocarbon age ranging from 678 to 921 cal BP (sample T2-RC4 in Table 1).

The youngest deposit in the trench, colluvial Unit 1, is a poorly sorted, matrix supported, cobbly, gravelly, silty, clayey fine and very fine sand. Unit 1 is up to 20 to 30 cm thick near the fault, tapers westward, and pinches out within 5 m of the fault. A bulk sample of the lower part of Unit 1 yielded a radiocarbon date of 520 to 726 cal BP (sample T2-RC3, Table 1).

Structure: A 17-m-wide, northeast-striking fault zone was exposed by Trench 2 (Plate 3). Most of the exposed structures are near vertical faults and fractures, with little to no vertical offset along them. The main fault juxtaposes highly sheared Tertiary sandstone against the stack of colluvial and alluvial deposits (described above) and it is associated with numerous secondary faults of anatomizing character. The main fault zone (faults F2a & F2b, and antithetic faults F2c and F2d) strikes N15 E (varying between 11 and 15), parallel to the fault scarp and coincident with the lower third of the scarp face, and dips from 74 W to vertical. Most secondary faults within the zone strike more easterly (N30 to 35 E) by approximately 15 to 20 , similar to trench 1 fault orientations and consistent with Reidel shears in a right-lateral fault zone. The fault plane was exposed with hand tools in a unfruitful effort to reveal shear-sense indicators. There is a penetrative fracture zone in the Tertiary sediments that extends about a meter east of the main fault, and is probably the result of many earthquakes, prior to the deposition of the latest Quaternary deposits.

A second fault zone (fault F7) strikes N18 to 24 E, which is more easterly than the main fault. Strike-slip displacement is suspected across this zone because of juxtapositions of units across it.

The dip of Fault F11, 76 E, suggests that it has an antithetic relationship to the main fault. However rather than exhibiting antithetic normal offsets, this secondary fault has 10 to 30 cm of apparent reverse offset. The near-vertical fault bounds the west edge of a slightly east-tilted block, which extends to the main fault and is composed on Units 7 through 4, and possibly Unit 3. A young fissure filled with Unit 2 deposits suggests a component of extension across Fault F11 as well. The apparent reverse offset and seeming incompatible extensional component, along with the mismatch of units across the fault, suggest strike-slip motion.

Paleoearthquake History: Three to five paleoearthquakes have offset late Quaternary deposits exposed in Trench 2. For ease of discussion these earthquakes are designated as Paleoearthquakes 1, 2, 3 and possibly 4. The most-recent event, or Paleoearthquake 1, also was identified in nearby Trenches 1 and 3, and paleoearthquakes 2 through 4 were identified in Trench 3, based on stratigraphic, soil-stratigraphic and geomorphic relationships, supported by four radiocarbon dates to date. Evidence for past earthquakes includes colluvial wedges, a single-event fault scarp, fault fissures, and upward-terminating fault traces.

Paleoearthquake 1 created the distinct young surface rupture that extends through the site (Plate 1). These scarp features are associated with a still-developing colluvial wedge deposits (Unit 1). Most of the offset during the event occurred along the main fault zone (faults F2a & F2b). This event created more than 40 cm of apparent vertical offset of the exposed trench deposits. Paleoearthquake 1 occurred between 678 to 921 and 520 to 726 cal BP, based on bracketing radiocarbon dates from Units 1 and 2a (samples T2-RC3 and T2-RC4, respectively).

The colluvial deposit associated with Paleoearthquake 2 has a cobbly proximal facies and distinct buried stoneline. Several adjacent secondary fault traces (faults F2c, F2d, F3, F4a, and F4b) also appear to have had minor offsets during Paleoearthquake 2. Minimum estimates of apparent vertical offsets from Paleoearthquake 2 range from 90 to 110 cm.

Paleoearthquake 3 created a topographically low space where hypersaturated alluvial deposit Units 3a accumulated and triggered colluvial deposition of Unit 3b. Unit 3a and 3b make up a total thickness of approximately 1 m and pinches out within 6 m of the fault. Removal of Paleoearthquakes 1 and 2 gives a minimum apparent vertical offset of ~110 cm; this is a minimum because it is uncertain how much strata has been removed by erosion from the footwall.

Paleoearthquake 4 is suspected base on an apparent fissure-fill deposit along fault F2c, Unit FF (Plate 2), and the colluvial-wedge appearance of overlying Unit 4. The uncertainty is how much younger is the fissure fill, which is older than Paleoearthquake 3, then Unit 4. It seems likely that the two are comparable in age, given that the fissure fill is position immediately below a small block of Unit 4 caught up in a slice along the fault. However, we can not discount that the fissure fill may significantly predate Unit 4. Thus, Unit 4 might be associated with Paleoearthquake 4 and the fissure fill may be also be related to this or to an earlier event, Paleoearthquake 5.

Older paleoearthquakes are potentially indicated by progressive offsets along secondary faults, although lateral offsets or upwards dying offset during younger events (PE 1-4?) might also explain these observations. The faults that show potential progressive offset are faults F7a, F7 and F9, and possibly along faults F3, F5 and F6.

Trench 3

Trench 3 was located across the lower part of a large compound scarp bounding the highest (oldest) of the three offset, late Quaternary terrace remnants (fig 2). The compound scarp strikes N2 E and exhibits small steps and other geomorphic irregularities associated with the young surface rupture at the site. The trench was 39 m long, more than 4 m deep in a few places, and was oriented N88 W. The location of Trench 3, which is shown on Plate 1, is 38 59.325' N., 119 38.985' W based on a handheld GPS unit. The graphical log of Trench 3 is shown as Plate 4.

Stratigraphy: Four packages of deposits were exposed in Trench 3: 1) Tertiary sandstone in the footwall; 2) older alluvium overlying the sandstone; 3) alluvial deposits of the hanging wall; and 4) overlying colluvial deposits related to normal displacement along the main fault (discussed below).

The oldest deposits are gray, Plio-Pleistocene sandstones. These are finely to moderately bedded and massive, well sorted, medium to very fine sands. The sandstone has moderately spaced fractures throughout, and concentrated fracture zone proximal to the exposed faults. A lighter colored portion of the Tertiary sandstone (Unit 14a) showed some of the offset, much of which occurred before the overlying Quaternary sediments were deposited.

Older Quaternary alluvium is preserved in the upper part of the footwall (Units 10, 11, 12, 13, and 13a). This footwall alluvium is made up of moderately well to well stratified sandy gravels and gravelly sands associated with the highest terrace. These gravels range from well sorted pockets to poorly sorted layers, and most clasts are subrounded. The alluvium was deposited prior to formation of the compound scarp, based on the orientation of the associated alluvial channels which show flow was parallel to the scarp. The alluvium has carbonate lamina within and below it and a well developed Bt horizon in its upper part.

The oldest deposits in the hanging wall are a series of alluvial, fluvial and colluvial deposits (Units 4 through 9). These deposits are moderately to poorly sorted, commonly matrix supported gravelly sands. Fluvial portions are moderately well stratified. In general these deposits are more fluvial in nature to the west, away from the main fault, but there are some fluvial deposits proximal to the main fault that appear to have been deposited by stream flow parallel to the fault (e.g., Unit 5). The units commonly grade upwards from a fluvial lower part and to more massive possibly colluvial upper part. The fluvial deposits were either derived from the small incised drainage in the footwall, that at the time may have been flowing over what is now the middle terrace, or they were deposited by Buckeye Creek, a stream flowing parallel to and west of the fault (Plate 1). Colluvial deposits likely came from a preexisting compound fault scarp, but are difficult to assign to paleoearthquakes because of potential fluvial erosion and lack of exposure adjacent to the fault. Unit 4 is a poorly sorted, matrix supported deposit with 25 to 40%, rounded to subangular gravel, and tapers away from the fault.

Three packages of colluvial deposits occur adjacent to the fault, Units 1 through 3. The oldest set is Units 3, 3a, and 3b. Together these units define a classic colluvial wedge deposit with proximal (Unit 3a) and distal facies (Unit 3b). The overall unit is a massive, poorly sorted, matrix supported deposit with 7% to 20% rounded to subangular gravel clasts. In Unit 3a, the coarse component include cobbles and makes up 30% of the deposit, with some slope parallel fabric. Unit 3b is 70% to 80% fine sand indicating a large eolian input.

Units 2a, 2b, and 2c make up the overlying colluvial wedge package. Unit 2a is an eolian-rich Av horizon, Unit 2b is Bt horizon, and Unit 2c makes up most of the deposit. Unit 2c is a massive, gravelly very fine sand. The deposit has a proximal facies that is poorly to moderately sorted, and as much as 20% gravel and cobbles, with slope parallel fabric. The distal facies make up most of Unit 2c and have a large eolian component, as indicated by a high very fine sand component and only 1% gravel. Apparently the lift over the scarp created from the dominant wind direction (from the west and southwest, roughly perpendicular to the fault scarp) and a sand source created a buttress of very fine sand in this part of the wedge. Because of the large eolian component we asked Dr. Glen Berger of the Desert Research Institute to attempt to do a photon-simulated luminescence (PSL) date of this unit, assuming there was a good chance for resetting during eolian transport. The PSL sample was collected and is being processed.

Structure: Faults were found throughout Trench 3, but most are small secondary structures with limited offset (<0.5 m). The zone of late Quaternary faulting is 25 m wide and consists of numerous near vertical to moderately steeply west-dipping faults and fractures. Nearly all of the recent displacement occurred on the main fault, fault F5. This fault strikes N5 E, essentially parallel to the fault scarp, and separates gray Tertiary sandstones in the footwall from brown colluvial and alluvial deposits mainly in the hanging wall. The fault dips about 80 to the west and has numerous synthetic faults splaying upwards into the hanging wall, forming an overall deformation zone as much as 3 m wide. Slivers of deposits caught between splays and the main fault are internally sheared and appear to have been wrenched. Total apparent vertical offset is greater than the 4 m depth of the trench.

There are several secondary faults in the hanging wall typically are spaced from 0.5 to 1 m apart. Most are simple faults with little offset, some have echelon steps, and one has progressive offset with depth (fault F10; greater apparent offset of the base of Unit 8 verses the base of Unit 7).

The main fault (fault F5) and fault F14 bound a 13-m-wide tilted block, which has been slightly broken by secondary faults and shows evidence of progressive tilting of Units 8 and 2c.

Secondary faults in the hanging wall consistently are oriented more easterly than the main fault, indicating they form a left stepping *en echelon* pattern, consistent with right-lateral wrench faulting of the hanging wall.

Paleoearthquake History: Evidence for at least three to four paleoearthquakes is exposed in Trench 3, and there is likely evidence for older events as well. Again, these events are numbered Paleoearthquakes 1 through 4 (youngest to oldest). Paleoearthquake 1 produced the young rupture fault scarp, which at trench 3 is about 1 m high across the mid-slope of the oversteepened base of the large compound fault scarp. Unit 1is an incipient colluvial-wedge deposit associated with the most-recent event that buries the next oldest colluvial-wedge deposit. Offset during Paleoearthquake 1 was complex and one fault near the upper part of the scarp (upper part of Fault F5b) has an apparent reverse offset of 15 cm. In contrast, at fault F14 a fissure opened approximately 12 cm during Paleoearthquake 1. Faults that moved during Paleoearthquake 1 include faults F5a, F5b, F5d, F8, F9, F14, and possibly F13. Within the main shear zone there are some areas of very young shearing with loose open framework, such as area A; these are attributed to Paleoearthquake 1.

Paleoearthquake 2 produced at least 1 m of vertical offset, and probably a little more based on the thickness of the associated colluvial wedge, Unit 2. The main evidence for this event is the classic colluvial wedge deposit (Unit 2), that is as much as 1.4 m thick near the fault. In addition, a ~20 cm wide fissure also opened during Paleoearthquake 2 along Fault F5e. Other faults involved in Paleoearthquake 2 include faults F5c, F5d, F6, F7, F8, F9, F10, and possibly faults F13 and F14.

Paleoearthquake 3 also formed a fault scarp that was subsequently eroded and formed a classic colluvial-wedge deposit (Unit 3). This deposit is as much as 0.9 m thick near the main fault, and tapers away to zero thickness approximately 8 m west of the fault. The deposit has a well developed proximal facies wedge (Unit 3a), created from scarp collapse, and a distal facies (Unit 3b), that has an eolian, fine sand component. Faults that moved during Paleoearthquake 3 include faults F6, F7, F5d, and possibly F5e and F11.

Paleoearthquake 4(?) is suggested by the wedge shape and character of Unit 4, which is 60 cm thick near the main fault and pinches out about 6 m to the west. The event is also suggested by the apparent back-tilt of the base of Unit 4. Furthermore, faults F6 and F7 appear to have progressive with larger offsets near the top of Unit 5 the in Unit 4 that may be related to Paleoearthquake 4(?). The fissure along fault F11 was created during Paleoearthquake 3 or possibly 4, but the later is preferred because the fissure fill is more akin to Unit 4 than Unit 3.

Earlier, paleoearthquakes are potentially indicated by progressive offsets along faults, upward terminating fault traces, and associated colluvial deposits. Because there is stratigraphic order to the deposits, possible older paleoearthquakes are continued in the numbering sequence with question marks. Paleoearthquake 5(?) is indicated along fault F8a, which has a small offset in Unit 6, but terminates at the base of Unit 5. Paleoearthquake 6(?) ruptured faults F12a and F12d which offset Unit 7, but not Unit 6. Paleoearthquake 7(?) offset Unit 7 across faults F12b, F12c, F13a, but did not offset Unit 7. Other faults likely moved during these paleoearthquakes, but they have been overprinted with more recent earthquakes.

Trench 6

Trench 6 was approximately 6 m long and was oriented N85 W across a low but fairly distinct scarp associated with the most recent event on one of the more prominent faults within the western group of young surface ruptures (Plate 1). The location of Trench 6, 38 59.772' N., 119 43.112' W, is shown on Plate 1, and the log is shown on Plate 5. A reconnaissance level effort was permitted at this site when we were unexpactently granted about an hour to excavate and log a trench at a site to be deeply plowed immediately following our brief trenching effort. The short trench revealed faults that moved during the most recent event, the target of this trench. The N5 E-trending scarp shows up on low-sun-angle photography crossing young, inset alluvial deposits. Although the land had been used for small-scale farming and grazing, the 55- to 70-cm-high scarp was only slightly modified. Stratigraphic offsets measured in the trench are slightly less, approximately 55 cm. The height of the scarp appears to results from both discrete offsets and slight footwall warping, or has been exaggerated by eolian processes or cultural activities.

Stratigraphy

Trench 6 exposed young alluvial sediment with thin sand layers and thin soil horizons with weak structure. The deposits are made up of silts and fine and very fine sands, and are probably largely reworked eolian material washing down from surrounding slopes. The presence of weak soil structure indicates short periods of relative surface stability.

Structure

Three small faults and minor warping was revealed in Trench 6. Deposits in the lower third of the trench exhibited minor offsets along two or three faults, F2, F3 and possibly F1. The upper deposits appear to draped and buried a small fault scarp. Fault F1 is vertical near the base of the trench and rolls slightly eastward near its top. The fault is cut into by a krotovina, and is part of a small down-to-the-west warp with an apparent vertical displacement of 25 cm. Fault F2 is vertical and has approximately 10 cm down-to-the-west apparent vertical offset. Fault F3 is vertical with approximately 20 cm of down-to-the-west apparent vertical offset and some slight reverse drag folding of stratigraphic layers adjacent to the west side of the fault. Taken together this deformation adds to an apparent, down-to-the-west vertical offset of ~55 cm, not considering the possible reverse drag. This is 10 cm less than the surface scarp height, resulting in a mismatch of less than 20% between the height and the offset.

Paleoearthquake History

Only the most recent event was exposed in Trench 6 as expected in such young sediment. Evidence for the earthquake includes faulted and warped deposits and the upward termination of faults. Bulk samples were taken from deposits that both pre- and post-date Paleoearthquake 1, but these have not been submitted for radiocarbon dating yet. This event offset the alluvial deposit down-to-the-west about 55 cm, in an apparent vertical sense.

SEISMIC HAZARD IMPLICATIONS

This study constrains the seismic potential of the ECVFS through surface-rupture length and surface displacement. Surface-rupture length can be constrained by considering the total length of the mapped fault system and the length of recent surface-faulting. The total length of the system places an upper bound on earthquake size, unless the system is involved in a cascading failure with an adjacent fault, a scenario not considered here. The total length is 21 to 26 km. There are two potential groups of young surface ruptures, although they may all be related to the same paleoearthquake (see yellow highlighted fault traces on Plate 1). The extent of the surface ruptures are minimums because only the larger offsets can be recognized; thus young surface faulting was longer than portrayed. The lengths of the two groups are 9 and 11 km, and the overall, end-to-end length of the young surface ruptures is 18 km. Thus rupture lengths of 9 to 26 km were used as one method of estimating paleoearthquake size (discussed below).

Coseismic surface displacements, constrained by trenching exposures, were also used to estimate earthquake size. All the measurements are apparent fault throw, but a lateral component is likely, and if correct would mean larger net slip. Coseismic fault offsets can be measured directly, such as in Trench 1, or inferred from colluvial-wedge thickness. In Trench 1 the most recent event offset units 82 to 90 cm in an apparent vertical sense; this was likely at least 1 m net slip. Colluvial wedges exposed in the trenches are up to 1.4 m thick, suggesting a similar amount of vertical displacement to twice as much, or more in the case of compound scarps. However without accounting for back-tilting, these are maximum values. For example, in Trench 3 back tilting during Paleoearthquake 2 accounts for approximately 40 cm of the about 150 cm offset suggested by the wedge thickness, or about 27%. This amount is likely made up by strike-slip faulting, however. Thus, minimum estimates of surface displacement range from 1 to about 3 m, with a mid value of 1.5 m; these are minimums because parallel faults rupture during earthquakes and cumulative displacements should be used, and these displacements do not include lateral components.

Using Wells and Coppersmith (1994) these lengths and displacements can be correlated with earthquake moment magnitudes. For fault surface rupture length in multiple environments, and for all displacement types the relationship is, $Mw = 5.08 + 1.16 \log(L)$, and with the same parameters for displacement the relationship is, $Mw = 6.69 + 0.74 \log(D)$. Using these relationships and the lengths and displacements given, potential earthquake moment magnitudes ranging from 6.1 to 7 are calculated. Considering a minimum for surface fault in the Basin and Range Province of about M6.3 to M6.5 (dePolo, 1994) this narrows the potential magnitude range to M6.3 to M7+ (Table 2). The displacement measurements are for a single fault trace and may be overall minimums if multiple fault traces are involved (the likely case).

Table 2 **Estimated Potential Earthquake Magnitudes for the Eastern Carson Valley fault system**

Length Estimated	Moment Magnitude*
9	6.1
11	6.3
18	6.5
21	6.6

26	6.7

Displacement	Estimated Moment Magnitude*
1	6.7
1.5	6.8
3	7.0

CONCLUSIONS

The ECVFS is a major earthquake source with an unusually high surface faulting hazard brought on by its highly distributed nature. Earthquakes with magnitudes of M6.3 to M7+ occur along the system and rupture in parallel and en echelon fault patterns. A 1:24,000 map of the ECVFS provided with this report can be used as a guide for development in the area to avoid surface rupture hazards. Multiple Holocene earthquakes have occurred along the ECVFS, with the most recent in the eastern part of the system occurring between 520 and 921 years before present. Pending radiocarbon dates will constrain other paleoearthquakes from this system. A right-lateral component to the Fish Spring Flat fault zone is indicated by the overwhelming dominance of secondary fault traces that strike more easterly than the main fault trace indicating a shearing action, particularly in the hanging wall.

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APPENDIX A

Eastern Carson Valley fault system
Trench 1
Unit Descriptions

Unit 1

Brown (10YR 5/3), well sorted fine sand with a few rounded and subrounded gravel clasts. Semi-massive with a few vesicles and moderately well developed, fine to medium platy structure. Weakly indurated with the upper 7 cm loose sand. Sediments make up the surficial layer at the site and likely has a significant eolian input.

Unit 1a

Brown (10YR 5/3) gravelly, silty sand; some parts are matric supported and some parts are clast supported. Unsorted and generally massive with some weak platy structure. Clasts are mostly rounded with some subangular clasts. Colluvial deposit from the most recent event.

Unit 2

Pale brown (10YR 6/3) silty fine sand with minor gravel (<2%) and lenses of gravelly coarse to medium sand. Generally massive and matrix supported. Some sands have fluvial cross laminations. Fluvial channel and over-bank flood deposits.

Unit 2b

Pale brown (10YR 6/3) gravelly sandy lenses with few cobbles. Matrix supported with 20% to 30% gravel clasts. Fluvial channel deposits. The lower 15 cm has a whitish color to it.

Unit 3

Light yellowish brown (10YR 6/4) gravelly medium to coarse sand with a pronounced cobbly, pebbly lense in the south wall of the trench. Poorly sorted with some small, thin pebble stringers. Overall unit matrix supported with gravel <2%. The gravel lense is clast supported with 70% rounded, subrounded, and subangular gravel. Gravel clasts are slightly iron stained.

Unit 3a

Light yellowish brown (10YR 6/4) gravelly fine to coarse sand (most grains are medium sand). Generally matrix supported with pea gravel lenses. Slightly hard, but mostly friable. Some minor carbonate near the base of the unit.

Unit 4

Dark yellowish brown (10YR 7/3) gravelly coarse to medium, very fine sand. Massive with gravel lenses (20% rounded and sub-rounded pebble gravel). Whitish carbonate matrix effervesces strongly with HCl.

APPENDIX B

Eastern Carson Valley fault system
Trench 2
Unit Descriptions

Unit 1

Dark brown (10YR 3/3) gravelly, silty, clayey fine and very fine sand. Massive sedimentary structure, matrix supported, poorly sorted deposit with 20 to 30%, subrounded to subangular pebbles and cobbles. Strong coarse blocky soil structure; slightly hard; slightly sticky; plastic. Lower boundary is abrupt and smooth. Colluvial wedge deposit formed following offset from the MRE.

Unit 2a

Dark gray (10YR 4/1) gravelly silty fine and very fine sand. Massive sedimentary structure, matrix supported, poorly sorted deposit with 30 to 40%, rounded and subrounded pebbles and cobbles. Weak, medium blocky soil structure with locally distinct fine platy structure near the top; locally vesicular; hard; slightly sticky to non-sticky; slightly plastic. Smooth, clear lower boundary. The deposit is colluvium with an eolian input, and in places is a buried Av horizon.

Unit 2b

Brown (10YR 5/3) gravelly, clayey fine sand. Massive sedimentary structure with a basal stoneline. Matrix supported, poorly sorted deposit with 20 to 30%, subrounded to rounded pebbles and cobbles. Well developed, coarse and medium prismatic structure; sticky and plastic. Lower boundary is abrupt and smooth. The deposit is a colluvial wedge formed from Paleoearthquake 2.

Unit 3a

Yellowish brown (10YR5/4) gravelly, clayey fine and very fine sand. Massive sedimentary structure, moderately to poorly sorted, matrix supported deposit with 10 to 15%, subrounded to subangular gravel with infrequent cobbles. Weak medium blocky soil structure; slightly sticky and slightly plastic. Lower boundary is smooth and abrupt. Colluvial deposit.

Unit 3b

Strong brown (7.5YR 4/4) cobbly, gravelly, clayey coarse to very fine sand. Crude sedimentary layering with some imbricated clasts in a moderately sorted, clast supported grading upwards to matrix supported deposit with ~50% subrounded and subangular pebble gravel and infrequent cobbles. Massive soil structure; slightly sticky; plastic to slightly plastic. Lower contact is clear and wavy. Hyperconcentrated alluvial deposit.

Unit 4

Light yellowish brown (10YR 6/4) gravelly clayey fine to very fine sand. Massive sedimentary structure, poorly sorted, matrix supported deposit with 20 to 30% gravel and cobbles. Massive soil structure with some weak small blocky structure; slightly sticky; plastic; slightly effervescent with HCl. Lower boundary is abrupt and smooth. Colluvial deposit.

Unit 4a

Very pale brown (10YR 7/3) clayey, medium and fine sandy gravel. Massive sedimenatary structure, moderately sorted, matrix supported deposit with 50 to 75 %, subrounded and subangular gravel. Massive soil structure; slightly hard; slightly sticky; plastic; no HCl reaction on matrix, but strong reaction on rare carbonate coatings on clasts. Abrupt smooth lower boundary. Debris flow or hyperconcentrated alluvial deposit.

Unit 4b

Light yellowish brown (10YR 6/4) clayey, coarse sandy gravel. Stratified, clast supported, moderately well sorted deposit with 60% to 70% subrounded and subangular pebble gravel with layers and lenses of increased matrix material. Massive to single grain soil structure; loose to slightly hard; non-sticky; non-plastic; slight HCl reaction. Lower contact is smooth and clear. Fluvial alluvium with a hyperconcentrated alluvial upper part.

Unit 5

Very pale brown (10YR 7/4) clayey sandy gravel to gravelly clayey sand. Weakly to moderately stratified, clast supported with some matrix supported layers, poorly sorted deposit with 70% to 80%, subrounded pebble gravel. Massive soil structure; non-sticky; slightly plastic. Lower boundary is abrupt and wavy. Fluvial deposit.

Unit 5a

Very pale brown (10YR 7/4) clayey, sandy fine to medium gravel. Distinct to crude stratification, clast supported with some open clast supported interbeds, moderately well sorted deposit with 75% to 85%, subrounded and subangular gravel. Massive to single grain soil structure; slightly hard to hard; non-sticky; non- to slightly plastic; strong HCl reaction in the coarser western 2/3 of the exposure. Slightly irregular, clear lower contact. Generally finer upward fluvial deposit.

Unit 6

Very pale brown (10YR 7/3) gravelly, clayey fine sand. Massive sedimentary structure, matrix supported, poorly sorted, 20% to 30%, subrounded and subangular gravel. Coarse blocky soil structure; hard; non-sticky; non-plastic; slightly effervescent with HCl to strongly effervescent coats on ped faces and clasts. Colluvial deposit that grades westward to alluvium; truncated Bk paleosol.

Unit 6a

Very pale brown (10YR 7/3) sandy gravel with cobbles. Crudely to moderately stratified with some possible imbricated clasts, clast-supported with parts that are matrix supported, poorly to moderately sorted, 60% to 80%, subrounded to subangular gravel and cobbles. Single grain without obvious soil structure; non-sticky; non-plastic. Alluvial to hyperconcentrated alluvial deposits.

Unit 7

Strong brown (7.5YR 5/6) gravelly medium to fine sand. Massive sedimentary structure, matrix supported 5% to 15% rounded to subrounded clasts. Discountinuous weak medium blocky and weak prismatic structure, with some carbonate stringers. Colluvial deposit, with minor alluvial, and eolian? components.

Tertiary Alluvium (Ts)

Light gray (10YR 7/2) medium to very fine sand with minor pebble stringers. Medium to thinly bedded, <5% sandy pebble lenses. Overlain by a compound soil including an Av horizon and two Bt horizons. Alluvial and fluvial sandy deposits.

APPENDIX C

Eastern Carson Valley fault system
Trench 3
Unit Descriptions

Unit 1

Brown (10YR 5/3) gravelly, silty sand. Massive sedimentary structure, but gravels have slope parallel fabric. Poorly sorted, mostly matrix supported deposit with 10% to 20%, well rounded to angular, granitic and metamorphic gravel clasts. Weak medium platy soil structure with a few vesicles; slightly hard, weakly indurated to friable. Abrupt, distinct lower contact. Colluvial wedge deposit from Paleoearthquake 1.

Unit 2a

Yellowish brown (10YR 5/4) medium to fine sand with some gravel clasts. Massive sedimentary structure, poorly sorted, matrix supported deposit with 2% to 5%, subrounded and rounded gravel clasts. [soil structure] Moderately gradational, even lower boundary. Upper part of a colluvial wedge deposit from Paleoearthquake 2 with a significant eolian input. The surface on this deposit was buried by the most recent earthquake's colluvial deposit.

Unit 2b

Light yellowish brown (10YR 6/4) sandy clay with some gravel and cobble clasts. Some slope parallel sedimentary fabric, poorly sorted, matrix supported deposit with 5% gravel and cobble clasts. Well developed, medium to fine prismatic structure; sticky; very plastic. Slightly irregular, gradational lower contact. Argillic horizon on top of colluvial wedge from Paleoearthquake 2.

Unit 2c

Brownish yellow (10YR 6/6) gravelly very fine sand. Increase of clast size from pebble gravel to cobble size near the main fault. Massive sedimentary structure, with strong, slope parallel fabric, poorly sorted , generally matrix supported deposit with 15% to 20% gravel clasts. 1% gravel in distal part where eolian input is large. Massive, well indurated unit with slight effervescence with HCl. Fairly even, abrupt lower contact. Colluvial wedge formed from a fault scarp created by Paleoearthquake 2; proximal and distal facies present.

Unit 2d
Brown to dark brown (7.5YR 4-5/4) pebbly, sandy clay. Matric supported deposit with 1% to 5% gravel. Fine prismatic soil structure; very sticky; very plastic; clasts are iron stained and have clay films on them. Lower contact is gradational over ~10 cm and is fairly even.

Unit 3

Brownish yellow (10YR 6/6) gravelly, coarse to fine sand (mostly fine sand). Massive, poorly sorted, matrix supported deposit with 7% to 20%, rounded to subangular gravel clasts. Gravels are more numerous near the main fault. Massive soil structure; indurated but friable; few vesicles. Abrupt, even lower contact.

Unit 3a

Same as Unit 3, but with 30% gravel and few cobbles. Some slope parallel fabric.

Unit 3b

Same as Unit 3, but massive with 70% to 80% fine sand; large eolian input.

Unit 4

Brownish yellow to yellow (10YR 6-7/6) gravelly fine sand. Poorly sorted and barely matrix supported deposit with 25% to 40%, rounded to subangular gravel. Massive soil structure; indurated; few vesicles. Even, abrupt lower contact.

Unit 5

Brownish yellow (10YR 6/6) gravelly medium to coarse sand. Crudely, weakly stratified, poorly to moderately sorted, mostly matrix supported deposit with 50% to 70%, rounded and subangular gravel clasts. Single grained soil structure; loose to weakly indurated. Lower contact is abrupt, uneven, and an unconformity. Fluvial deposit.

Unit 6

Brownish yellow (10YR 6/6) gravelly fine to very fine sand. Crudely stratified, moderately to poorly sorted, matrix and clast supported portions, with rounded to subrounded gravel clasts ranging from 1% in the upper part to 50% in gravel lenses. Weak, medium prismatic structure. Lower contact is an irregular, abrupt unconformity. Lower part of unit is fluvial, upper part may have some eolian input.

Unit 6a

Brownish yellow (10YR 6/6) pebble gravel with pockets of coarse sand and granules. Moderately well developed stratification. Fluvial lower part of Unit 6.

Unit 7

Brownish yellow (10YR 6/8) clayey, fine to very fine sand. Crudely to moderately well stratified, poorly sorted, matrix supported deposit with 10%to 25% subrounded and rounded gravel clasts; base tends to be more gravelly. Massive to local, fine prismatic structure; slightly sticky; some weak carbonate stringers.

Unit 7a

Same description as Unit 7, but moderate to well developed fluvial sedimentary fabric, and 25% gravel.

Unit 8

Brownish yellow (10YR 6/6) gravelly coarse to fine sand overlying a gravelly sand base. Massive, poorly sorted, matrix supported deposit with 5% to 40% subrounded and subangular gravel clasts. Some weak prismatic structure; few carbonate stringers; some granitic clasts are grussy. Basal contact is an abrupt, irregular unconformity.

Unit 9

Light brown to brown (7.5YR 6-5/4) gravelly coarse to fine sand. Massive, poorly sorted, matrix supported deposit with 5% to 20 % rounded to subangular gravel clasts. Massive soil structure with local weak medium prismatic structure.

Unit 10

Dark yellowish brown (7.5YR 3-4/4) gravelly, sandy clay. Poorly sorted and matrix supported deposit with 5% and less gravel. Moderate to well developed prismatic structure; sticky; very plastic. Abrupt to gradational lower boundary. Footwall argillic horizon with a discontinuous Av in upper part.

Unit 11

Brownish yellow (10YR 6/6) gravelly coarse to medium sand. Poorly sorted and matrix supported deposit with 10% to 15% gravel clasts. Medium to coarse platy soil structure with some carbonate stringers and filaments and light coats of carbonate on the bottoms of some clasts. Lower contact is abrupt on layered carbonate.

Unit 12

Pale brown (10YR 6/3) gravelly fine sand. Moderately stratified, well sorted, matrix supported deposit with minor pebble gravel lens (2% pebbles). Lower contact abrupt on carbonate laminae.

Unit 13

Brown (10YR 5/3) gravelly coarse to medium sand. Moderately to well developed stratification, matrix supported with lenses that are clast supported, 5 % to 20%, rounded and subrounded gravel clasts, with a few cobbles up to 15 cm diameter. Clasts made up of metamorphic, volcanic, and granitic rocks. Cross-section of a fluvial channel that has been faulted.

Unit 13a

Same unit as Unit 3, but with a moderately well developed, coarse to medium platy soil structure.

Unit 14

Light gray to light brownish gray (10YR 7-6/2) medium to fine sand and very fine sand; minor pebble stringers. Massive with some fine laminar bedding. Highly sheared with some carbonate filled fractures. Sheared Tertiary sandstone in the footwall.

Unit 14a

Very pale brown (10YR 7-8/3) silty very fine sand. Finely bedded, well sorted deposit with <2% pea gravel and coarse sand lenses. Tertiary sandstone in footwall.

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