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Paleoseismic studies of the Peavine Peak fault

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PALEOSEISMIC STUDIES OF THE PEAVINE PEAK FAULT

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Abstract

The Peavine Peak fault is a prominent range-front fault located 5 km or less from downtown Reno in western Nevada, and it forms the southern boundary of several basins undergoing rapid suburban development. Surficial mapping and trenching along the Peavine Peak fault provide the first paleoseismic information on this significant seismic hazard. Two trenches revealed evidence of several Holocene surface-rupturing events, with an average vertical displacement of 1.5-2 m per event. With a fault length of about 20 km, the fault is capable of generating earthquakes of close to magnitude 7.

The range-front morphology of the Peavine Peak fault indicates much of the displacement is vertical, but there is indirect evidence that it also has a significant right-lateral component: 1) the fault strike is parallel to major strike-slip faults in the region; 2) the fault has a common left-stepping *en echelon* pattern; 3) there is an apparent pull-apart basin at the fault's north end; and 4) the subvertical dip and "flower-structure" nature of the fault zone exposed in the trenches suggests strike-slip motion. Assuming approximately equal components of normal and right-lateral offset, we estimate the cumulative net displacement at the trench site to be ~10 m. We therefore estimate a Holocene slip rate of ~1 mm/yr, indicating the Peavine Peak fault is one of the most active faults in the region.

Introduction

The Peavine Peak fault is a prominent range-front fault that bounds the steep northeast side of Peavine Peak in the urbanized north Reno area, western Nevada (Fig. 1). The fault is located 5 km or less from the downtown Reno area, and it forms the southern boundary of several basins undergoing rapid suburban development, including Cold Spring, Lemmon, and Golden Valleys.

The central part of the Peavine Peak fault forms a steep range front with fault facets and large scarps in alluvium (Fig 2). Despite this being one of the most significant active faults in the Reno area, no paleoseismic studies had been conducted on the fault prior to this project, and it represents one of the largest gaps in understanding of seismic hazards in western Nevada.

Aside from its own seismic hazard, the Peavine Peak fault is important because it is structurally related to the Carson Range fault system (CRFS), a Sierra Nevada frontal fault and the principal seismic hazard in western Nevada. Surface expression of the northern end of the CRFS terminates at the Truckee River, but it projects toward the southeast end of the Peavine Peak fault and the two fault systems bound areas of relatively high elevation to the west. The two systems are depicted on existing maps (e.g., Bonham and Bingler, 1973; Bingler, 1974; Bell, 1984) as separated by a 6 to 8 km gap, but they may be more closely linked by concealed fault traces.

Our previous studies suggest the CRFS has ruptured with belt-like behavior during the late Holocene (Ramelli and others, 2000). The Genoa fault, the most active part of the system, ruptured 500-600 yr BP and at about 2,000 yr BP (Fig. 1; Ramelli and others, 1999a). Studies in the Washoe Valley and Carson City areas (Ramelli and dePolo, 1997; Ramelli and others, 1999b) suggested event timing roughly similar to the Genoa fault, raising the possibility of belt-like behavior along the system. Three radiocarbon ages from trenches on the Mt. Rose fan indicate the most recent event along the northern part of the system occurred 900-1,000 yr BP. The ages of the most recent events along the southern and northern parts of the system appear to be distinctly different, but they are nonetheless temporally clustered relative to the average event recurrence, which we estimate to be at least a few thousands of years.

Geomorphic evidence, including fault facets, large fault scarps, and a steepened range front, suggest slip on the Peavine Peak fault is dominantly normal. However, the fault is oriented parallel to major right-lateral Walker Lane faults, including the Pyramid Lake, Warm Springs Valley, Honey Lake, and Mohawk Valley fault zones (Fig. 1), suggesting that it may have a component of right-lateral motion. Further, the Peavine Peak fault has a left-stepping en echelon pattern and an apparent pull-apart basin at its northern end, both of which strongly suggest a component of right-lateral displacement.

This project aimed to: 1) examine the paleoseismic history of the Peavine Peak fault through trench investigations and surficial mapping at selected sites; 2) evaluate whether the fault may have been involved in possible belt-like behavior observed to the south along the Carson Range fault system; and 3) determine whether slip on the fault is dominantly normal, as suggested by geomorphology, or strike-slip, as suggested by its orientation.

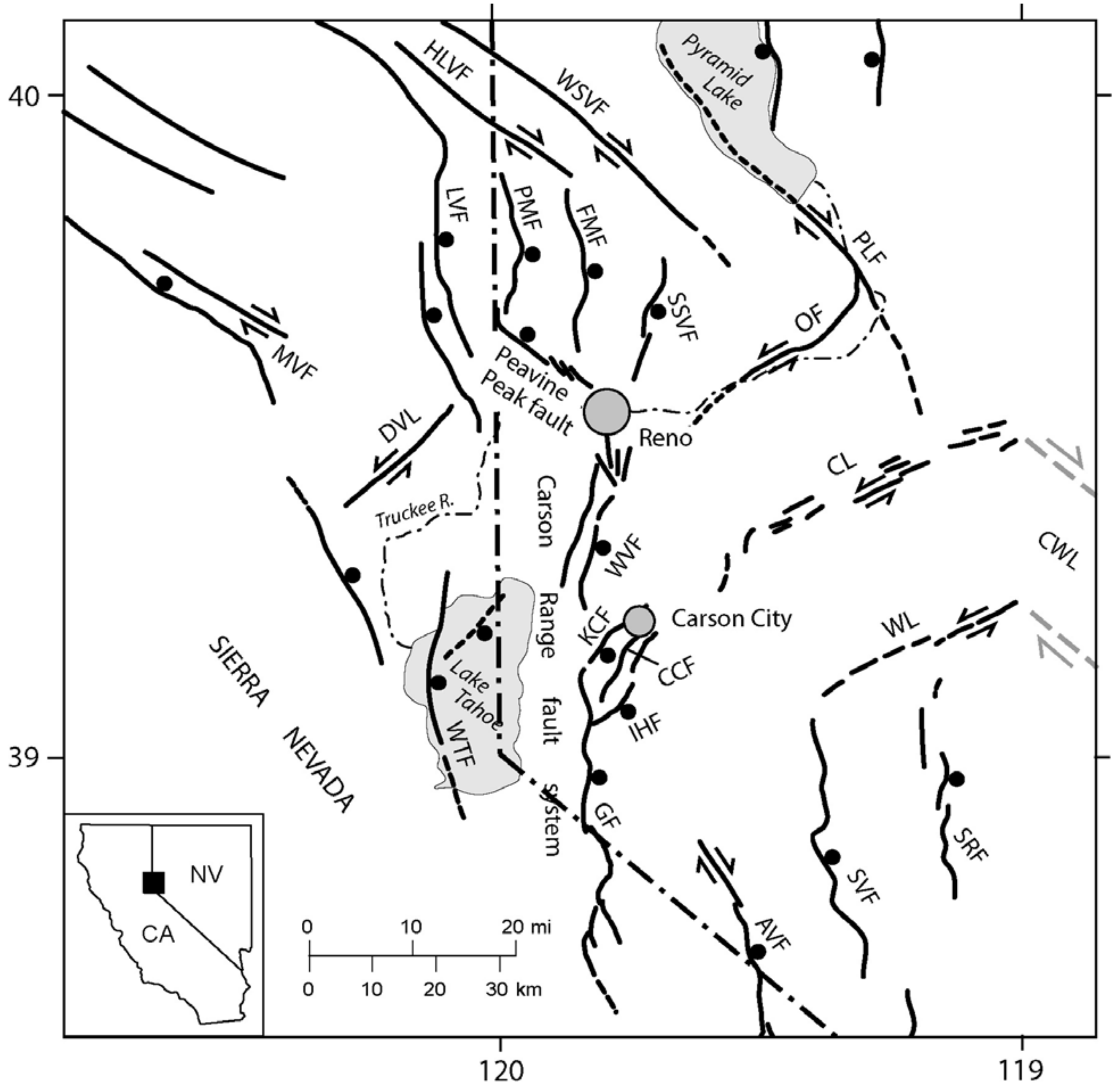

Figure1. Generalized map of Quaternary faults in western Nevada and eastern California. HLVF-Honey Lake fault; WSVF-Warm Spring Valley fault; PLF-Pyramid Lake fault; MVF-Mohawk Valley fault; LVF-Long Valley fault; PMF-Peterson Mountain fault; FMF-Freds Mountain fault; SSVF-Spanish Spring Valley fault; OF-Olinghouse fault; DVL- Dog Valley lineament; WVF-Washoe Valley fault; CL-Carson lineament; KCF-Kings Canyon fault; CCF-Carson City fault; IHF-Indian Hill fault; WL-Wabuska lineament; CWL-projection of Central Walker Lane; WTF-West Tahoe fault; GF- Genoa fault; AVF-Antelope Valley fault; SVF-Smith Valley fault; SRF-Singatse Range fault.

Seismicity of western Nevada

The western Nevada region has a high level of historical seismic activity that includes many large-magnitude events (Fig. 2), and two magnitude 6 earthquakes have occurred within 15 km of the Peavine Peak fault. Some background earthquakes (M<4) have occurred around the western half of the fault, whereas the area around the eastern half of the fault has a low level of seismicity. The largest historical earthquake proximal to the Peavine Peak fault is the 1995 M_w 4.5 Border Town earthquake (Ichinose et al., 1997), which had an epicenter about 2 km west of the northern end of the fault (Fig. 3).

Similar to much of the western U.S., Nevada has a short historical period. The first settlers arrived in the region in 1850 as a consequence of the California Gold Rush. Settlement increased with discovery of the Comstock Lode at Virginia City in 1860, but the population of the region remained low until well into the 1900s. Most of the larger historical earthquakes in the region occurred prior to the early 1900s. Because the area was so sparsely populated at the time, there are few accounts of these events and uncertainties about locations and sizes are very high. Instrumental seismicity became complete at a magnitude 3 level in about 1960, when seismographs were installed in western Nevada.

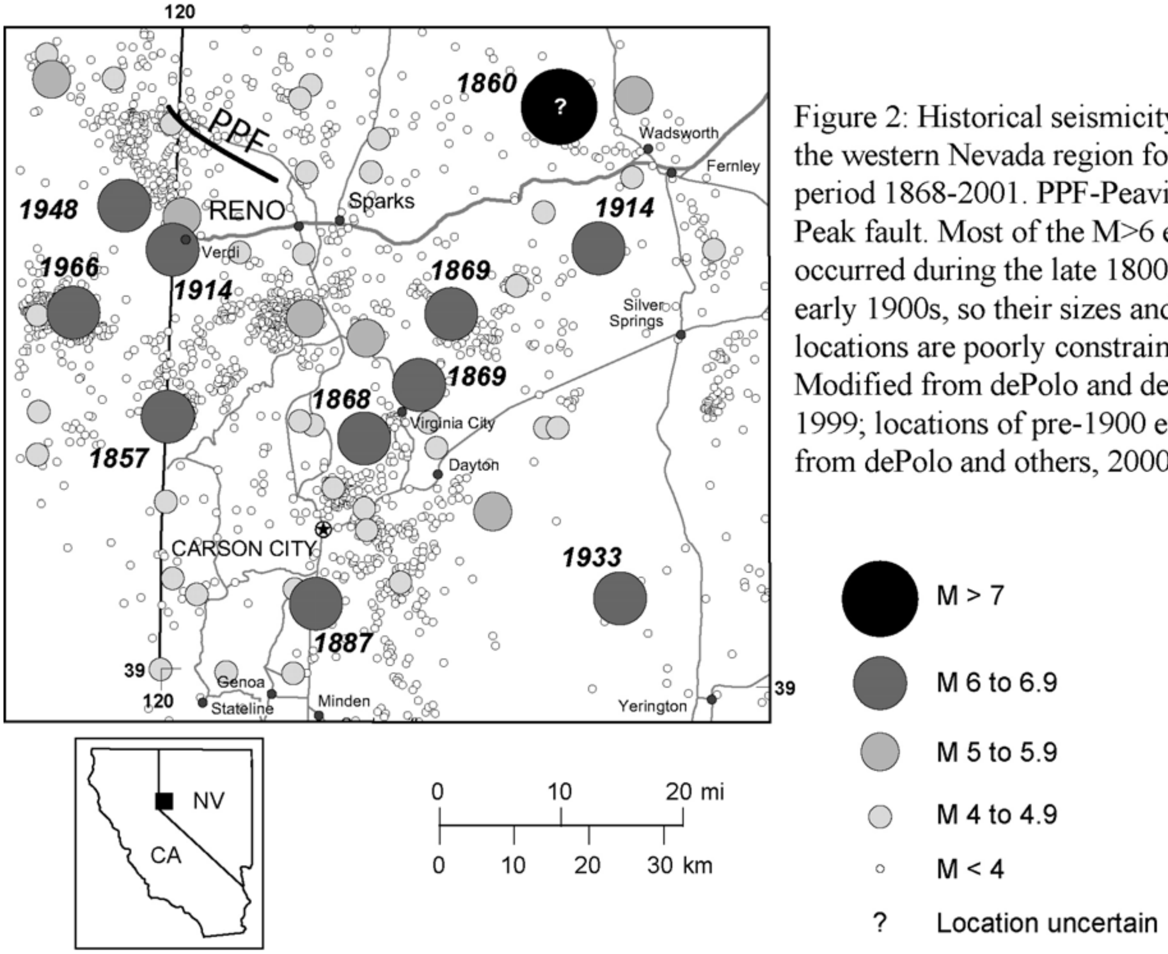

Figure 2: Historical seismicity in the western Nevada region for the period 1868-2001. PPF-Peavine Peak fault. Most of the M>6 events occurred during the late 1800s or early 1900s, so their sizes and locations are poorly constrained. Modified from dePolo and dePolo, 1999; locations of pre-1900 events from dePolo and others, 2000.

Figure 3. Aerial photograph showing northern Peavine Peak fault (bold lines), other faults (light dashed lines), and 1995 Border Town earthquake sequence (modified from Ichinose et al., 1997).

Geomorphic sections of the Peavine Peak fault

From analysis of geologic maps and aerial photographs, and field mapping, the Peavine Peak fault has a length of 17-20 km, extending from its apparent termination at the western margin of Cold Spring Valley on the north to its approximate intersection with the Carson Range fault system on the south. In the following discussion, we have divided the fault into four sections having differing geomorphic expressions (Fig. 4). No implications regarding earthquake segmentation are intended by these designations.

Lemmon/Panther Valleys section: The southeastern end of the Peavine Peak fault consists of several distributed fault traces that have more subdued expressions than the central part of the fault and that lack obvious recent scarps. These fault traces form a left-stepping *en echelon* pattern, suggesting an overall right-lateral component of displacement. Topographic relief across the section is at most about 300 m, and decreases toward the southeast. The southeast end of the fault is poorly defined, but is inferred to be at the projected intersection with the Carson Range fault system, 5 km or less from the downtown Reno area.

Peavine Peak section: North of the Lemmon/Panther Valleys section, the fault steps left approximately 2.5 km to a fault trace bounding the steep northeast side of Peavine Peak. This 3-km-long part of the fault has a prominent geomorphic expression, forming a steep mountain front, large fault facets, and obvious fault scarps in young alluvium. There is almost 700 m of topographic relief across this section, which occurs along the central part of the fault. Bouldery Pleistocene to Holocene alluvium is offset at several locations along this section (Bell and Garside, 1987), and has both multiple- and single-event scarps. This section is the primary focus of this study, including trench activities.

Dry Lake Summit section: Northwest of the Peavine Peak section, the fault extends into a landslide complex underlain by soft Tertiary sediments (Bell and Garside, 1987; Soeller and Nielsen, 1980). Some fault scarps can be traced into this landslide complex, but their expression is highly muted, and stratigraphic relations are greatly obscured. Similar to the Peavine Peak section, the Dry Lake Summit section bounds the prominent escarpment on the northeast side of Peavine Peak, and likely has similar activity. The most active central part of the fault (the Peavine Peak and Dry Lake Summit sections) is estimated to be about 7 km long.

Cold Spring section: The northwestern end of the Peavine Peak fault bounds the southwest side of Cold Spring Valley. North of the Dry Lake Summit section, there is a gap in surface expression across a broad alluvial-fan surface, north of which the fault bounds a low escarpment with as much as 60 m relief. The Cold Spring section lacks obvious recent scarps, but the escarpment locally has an inflection indicative of fault activity (Fig. 5). Cold Spring Valley is a closed basin with a lacustrine history and scarps may have been erosionally modified by pluvial lakes during the late Pleistocene. Soeller and Nielsen (1980) mapped beach deposits in the basin up to an elevation of about 1560 m, slightly above the surface trace of the fault. Based on fault geometry, Cold Spring Valley is likely a pull-apart basin resulting from right-lateral displacement.

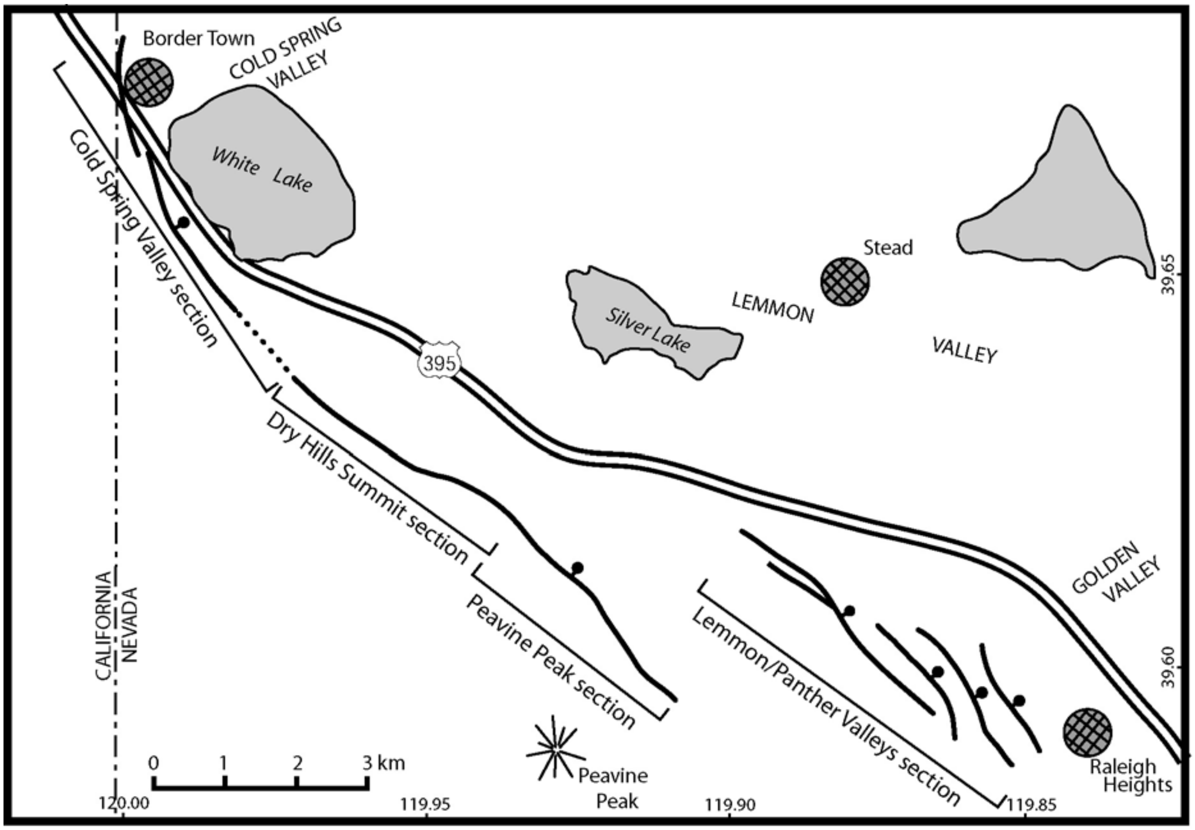

Figure 4. Geomorphic sections of the Peavine Peak fault

Figure 5. Photograph of inflection along escarpment in Cold Spring Valley, indicating fault activity. Photo taken 2.5 km south of Border Town. *Photo by A. Ramelli*

Trenching

We excavated two trenches at the head of an alluvial fan emanating from a small drainage about 3 km north of Peavine Peak (Fig. 6). The trench site is located along that part of the fault having the highest topographic relief (about 700 m), and it is not far from the midpoint of the Peavine Peak/Dry Hills Summit sections. Displacements at the trench site are therefore probably close to the maximum recorded along the fault.

Our original plan was to conduct trenching at one of the larger drainages along the Peavine Peak section of the fault. However, alluvium in all of these larger drainages consists of bouldery debris that would probably be difficult to excavate. For practical considerations, we therefore opted for a smaller drainage with cobble dominated gravels. During site selection activities, we considered and examined four sites at the larger drainages (sites A to D; Fig. 6). At Sites A and D, water lines are buried along or against the fault scarp. Surface disturbance is minimal at Site A, but a buried water line runs along the toe of the scarp. Also at Site D, mine tailings have been dumped on the fault scarp. Site B, although undisturbed, has only a single displaced terrace surface. We chose Site C, which is undisturbed and has two distinct offset surfaces, as the preferred site of the four. However, due to the abundant boulders at Site C, we opted for the small drainage immediately to the north.

The trench site has two uplifted inset fan surfaces that have only slight topographic separation (Figs. 7 and 8). Along all of the Peavine Peak section, alluvial-fan surfaces are largely smoothed and heavily vegetated, so distinguishing different-aged surfaces is difficult. As background work for a geologic map of the area (Bell and Garside, 1987), Bell examined soils along the range front and determined that the piedmont surface is dominated by Holocene deposits. Figure 7 shows generalized distinctions between younger and older Holocene alluvium in the vicinity of the trenches, but surface boundaries have large uncertainties.

Topographic surface profiles of the fault scarp at the trench site show about 4 m of vertical separation of the older surface and 2.5-3 m separation of the younger surface. The trenches exposed downthrown fan deposits buried by younger scarp colluvium, so the separations shown in the topographic profiles underestimate the actual vertical offset.

Stratigraphic and faulting relations are best exposed in Trench 1. Trench 2 was excavated in an attempt to expose the bedrock fault surface and therefore located on the margin of the alluvial fan adjacent to the hillslope. Trench 2’s location makes it less than ideal for evaluating faulted fan deposits, but it nonetheless exposed evidence of the three youngest faulting events and confirmed interpretations of Trench 1.

We had hoped to expose the bedrock fault surface to see if there were fault striations indicating the sense of slip on the fault. Unfortunately, neither trench exposed bedrock, and we can therefore only make indirect inferences about the possible component of lateral offset.

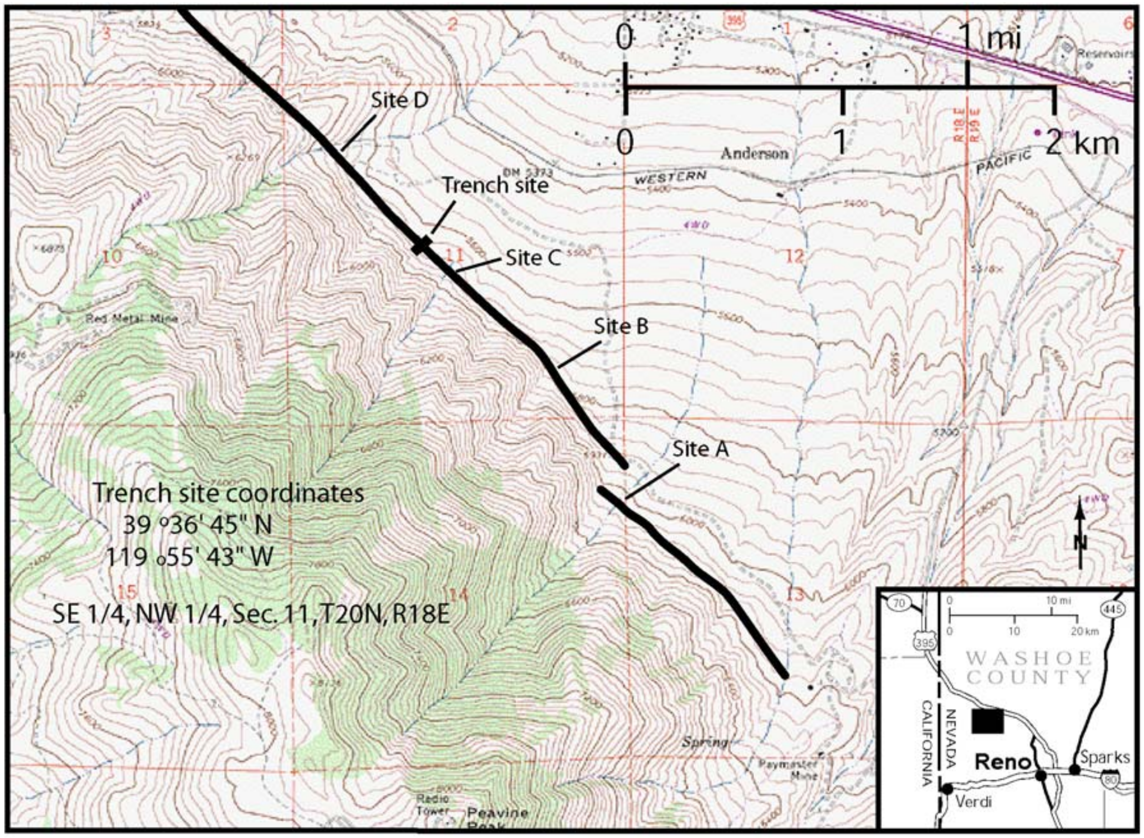

Figure 6. Trench site location map, Peavine Peak fault project

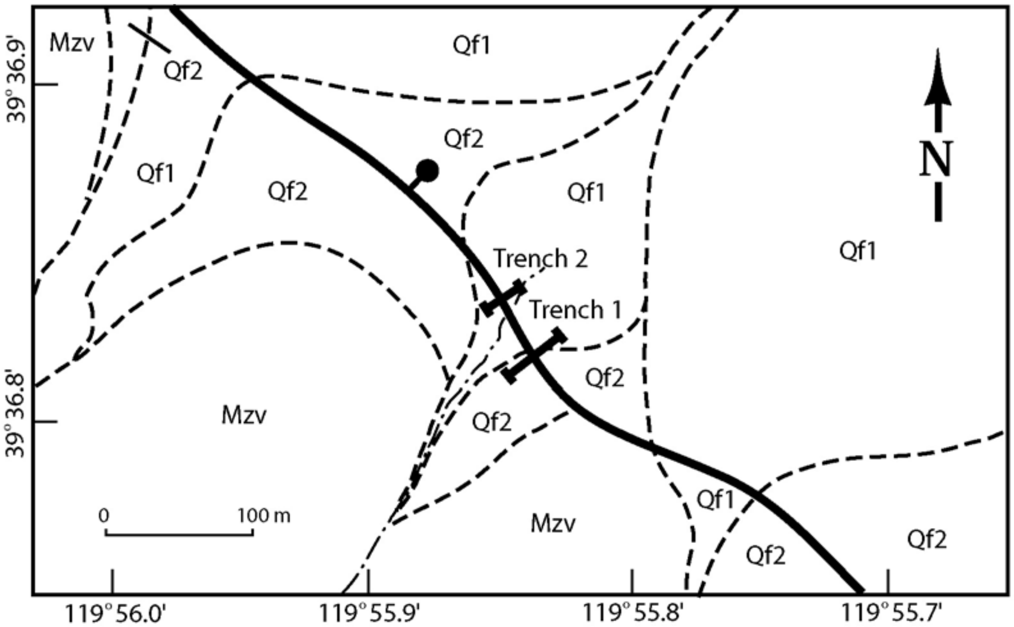

Figure 7. Generalized surficial geology map of the Peavine trench site. Qf1- mid- to late Holocene alluvium; Qf2- early to mid Holocene alluvium; Mzv- Mesozoic metavolcanics. Qf1 contacts are extended downslope to show approximate alluvial-fan boundaries.

Trench 1 stratigraphy

Trench 1 exposed offset fan deposits consisting of sandy cobble and pebble gravels (Plate 1). In general, all of these deposits are quite similar, but moderate stratification and local sorting allowed delineation of bedding planes and distinction of fan deposits from reworked scarp colluvium. The faulted fan deposits have a mollic soil, with a cumulate A horizon that is 0.5-1.5 m thick. On the hanging wall, the A horizon thickens toward the fault zone (Fig. 9). Below the cumulate A horizon, there is a weak cambic horizon, but no other indicators of soil development. There is also a cambic soil locally preserved at the top of the buried fan deposits on the hanging wall. Some gravel deposits have relatively large amounts of fine-grained matrix that may represent weak soil development, but none of these are distinct soil horizons. All of the observed soil relations are consistent with a Holocene age for the fan deposits. The distribution and dipping attitude of alluvium in the hanging wall indicate that nearly all of the deposits are fault scarp colluvium, and that the fan deposits are exposed only near the bottom of the trench.

Trench 1 structure

Trench 1 exposed a distinct, splaying-upward fault zone that records evidence of several events. The fault zone is 4-5 m wide, is located in the lower part of the scarp, and consists of two principal fault traces and a minor antithetic trace (Plate 1). Cumulative vertical offset is divided approximately equally between the two principal traces. The southern trace dips to the northeast and has a simple, single-event splay near its top; this trace was involved in most of the events, but not Event 1. The central trace has a near-vertical dip, forms a complex zone 0.5-1 m wide, and has two separate fissures in its upper part; this was the only trace involved in Event 1, which formed a fissure more than two meters deep, nearly one meter wide, and filled by dark, organic-rich soil material (Fig. 9). Event 2 formed a smaller fissure (about one meter deep and 0.3 m wide) on the central trace. Offset of fan deposits requires that the central trace was also involved in earlier events. The northern, minor antithetic trace dips southwest and has only about 0.2 m of down-to-the-southwest displacement; this trace was involved only in Event 3. Projection of the top of the fan deposits in the footwall indicates a cumulative vertical offset of 6-9 m (Plate 1).

From colluvial wedges, fault fissures, and truncated fault relations, we interpret three events in the uppermost few meters of Trench 1. The most recent event (Event 1) formed a large fissure (F1) that is buried by a small colluvial wedge (C1), and led to thickening of the cumulate A horizon; we estimate the vertical offset during Event 1 to be about 0.5 m. The penultimate event (Event 2) involved both of the principal fault traces, but most of the offset was on the southern trace; we estimate the vertical offset during Event 2 to be more than 1.0 m. Event 2 formed fissures on both traces (F2), and resulted in a colluvial wedge (C2) that extends to the toe of the scarp. A prior event (Event 3) produced a distinct cobbly colluvial wedge (C3). The limited extent of C3 indicates a smaller offset than Event 2, but the thickness of C3 requires a minimum vertical offset of 0.5 m. The presence of scarp colluvium below C3 requires additional colluvial wedge deposits that are poorly exposed at the bottom of the trench (represented by C4 on Plate 1). From the amount of offset required (2-4 m), it is likely that C4 includes two or more events of comparable size to Event 2. Average vertical offset is estimated to be 1.5-2 m per event.

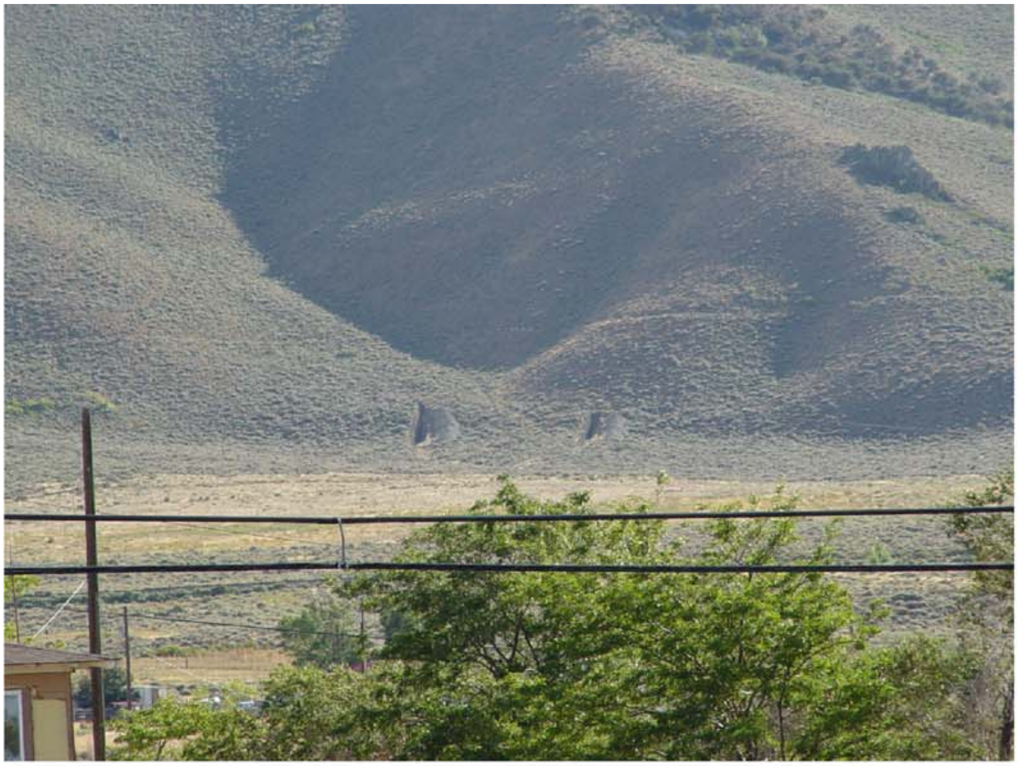

Figure 8. Peavine Peak fault trench site. *Photo by A. Ramelli*

Figure 9. Trench 1, Peavine Peak fault. Dark upper unit and fissure fill is mollic soil that thickens against the fault in response to MRE. *Photo by C. dePolo*

Table 1. Structural/stratigraphic relations in Trench 1

Depositional Event	**Faulting Event**	**Dating Sample/*Soil***
Thickening of cumulate A horizon downslope from fault		*Pebbly mollisol (cumulate A)* RC2: base of cumulate A horizon
Colluvial wedge C1		
Fissure fill F1	Event 1 (MRE)	RC1: Fissure fill F1
Cobbly colluvium draping scarp		*Cobbly mollisol*
Colluvial wedge C2		
Fissure fill F2	Event 2	
Scarp colluvium separating wedges C2 and C3		RC3: scarp colluvium
Colluvial wedge C3		RC4: colluvial wedge
	Event 3	
Scarp colluvium separating wedges C3 and C4		
Colluvial wedge C4		
	Event 4	
	Event 5(?)	
Alluvial fan aggradation		RC5: uppermost fan/*cambic horizon*
Alluvial fan aggradation		RC6: buried fan deposit
Alluvial fan aggradation		

Summary

Surficial mapping and trenching along the Peavine Peak fault provide the first paleoseismic information on one of the most active faults in western Nevada. Based on mapping, we estimate the fault length to be 17-20 km. Trenching revealed several Holocene events, with an average vertical offset of 1.5-2 m per event. Six bulk-soil samples were collected for radiocarbon dating, and results are pending. The average recurrence interval is currently poorly constrained, but appears to be on the order of 2000-3000 years. With a fault length of about 20 km, and offsets of about 2 m per event, the fault is capable of generating earthquakes of close to magnitude 7.

There is indirect evidence of a right-lateral component of displacement on the fault: 1) the fault strike is parallel to major strike-slip faults in the region; 2) the fault has a common left-stepping *en echelon* pattern; 3) there is an apparent pull-apart basin at the fault's north end; and 4) the subvertical dip and "flower-structure" nature of the fault zone exposed in the trenches suggests strike-slip motion. We estimate that the cumulative net offset at Trench 1 is ~10m (assuming a 45^o rake). Based on a Holocene age for the offset fan deposits, we estimate a Holocene slip rate of ~1 mm/yr, indicating the Peavine Peak fault is one of the more active faults in the region.

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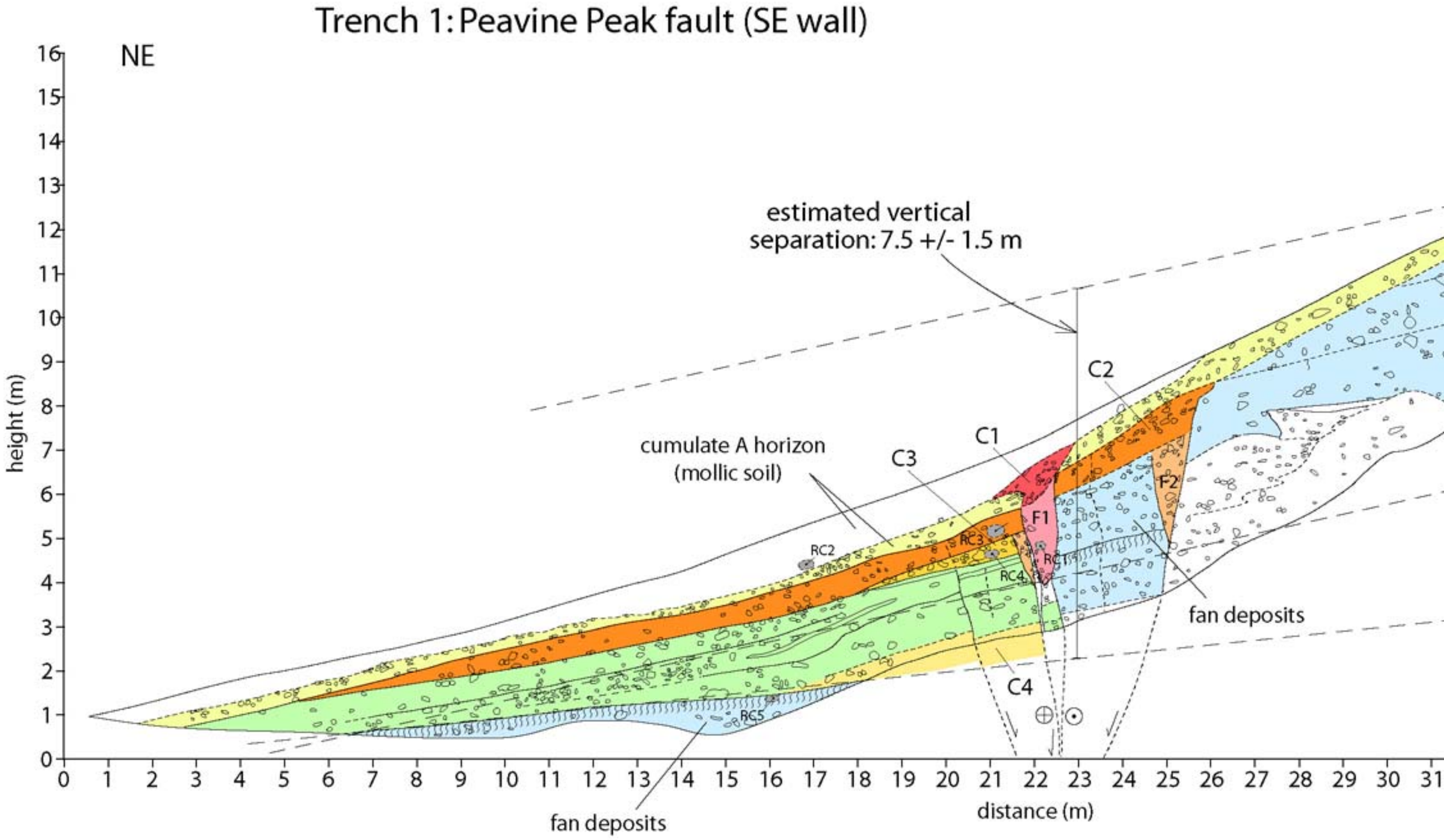

Plate 1. Log of southeast wall of Trench 1, Peavine Peak fault. Displaced fan deposits are estimat
based on soil development. Six bulk-soil samples were collected for radiocarbon dating. Vertical
may be somewhat less if hanging wall deposits are backrotated. Vertical separation should approx
fault dip. The fault is assumed to also have an unknown right-lateral component of displacement.
four or five events (represented by colluvial-wedge deposits C1, C2, C3, and C4; the latter probal