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Short Note

Range-Bounding Normal Fault of Smith Valley, Nevada: Limits on Age of Last Surface-Rupture Earthquake and Late Pleistocene Rate of Displacement

by Steven G. Wesnousky and Marc Caffee

Abstract Smith valley is bounded on its western edge by an active normal fault and the Pine Nut mountains. Displacement on the fault is responsible for development of one of the westernmost basins of the Basin and Range province of the western United States. Interpretation of an exposure afforded by excavation of a trench across the range-bounding fault places the most recent surface-rupture earthquake after 5176 ± 130 cal B.P. and suggests it was close in time to 3530 ± 82 cal B.P. Utilization of tephrochonologic and cosmogenic analyses and mapping of fault scarps across the Artesia Road fan are the basis for putting forth an initial estimate of the late Pleistocene vertical slip rate of the fault at between 0.125 mm/yr and 0.33 mm/yr.

Online Material: To be sent later.

Introduction

Smith Valley is one of the westernmost basins of the Basin and Range province and is located in the Walker Lane, a zone of disrupted topography that is generally characterized by north–northwestward oriented ranges and faults that follow the eastern edge of the Sierra Nevada (Fig. 1). Geodesy shows that approximately 1 cm/yr of Pacific–North America plate motion is localized in the Walker Lane (e.g., Thatcher *et al.*, 1999). With the intent of contributing information to seismic hazard analysis in the region and ongoing efforts to understand where and what portion of accumulating geodetic strain is released in earthquakes (e.g., Hammond and Thatcher, 2007), this note puts forth observations bearing on the age of the last surface-rupture earthquake and late Pleistocene slip rate of the Smith Valley fault.

Smith Valley is bounded on its western edge by an active normal fault and the Pine Nut mountains (Fig. 2). The valley floor sits at about 1400 m and the Pine Nut mountains reach elevations of approximately 2700 m. The fault is locally expressed by an abrupt rangefront, triangular facets, and scarps in young fanhead alluvium from a southern limit of ~38°40′ northward a distance of ~30 km to ~38°55′ (Fig. 2). At the latitude of ~38°55′, the fault may step eastward into the valley and scarps in young alluvium appear absent along a more sinuous rangefront. Scarps in young alluvium are again evident further north in the narrow valley between the Pine Nut mountains and the Buckskin range, extending to ~39°06′, bringing the total length of the fault system to 45–50 km.

Our observations result from the study of two sites along the fault zone. Site 01 is located a couple of kilometers north of where the West Walker river enters Smith Valley. Site 02 is located about 14 km to the north (Fig. 2).

Upper Colony Road Trench—Site 01

The fault trace follows a small reentrant just north of where the West Walker River enters Smith Valley (Fig. 2). Here, the fault is manifested by a clear ~3.5 m scarp in fan alluvium (Fig. 3). A sketch of the fault exposure produced by cutting a trench across the scarp is shown in Figure 4. The lowest beds across the exposure are designated unit 1 and are composed of alternating subhorizontal and commonly discontinuous beds of fine and coarse granitic gravel. Unit 1 is interrupted and displaced by several faults in the central portion of the log. The offset of unit 1 across the westernmost trace has dropped unit 1 downward east of the fault and produced a small triangular graben. The materials within and above the graben are labeled unit 2 and consist of granitic gravel identical to unit 1 but distinguished by a lack of bedding and massive character. Localized, weak cut, and fill fabric within unit 2 is interpreted to suggest that emplacement was by alluvial as well as colluvial processes.

Unit 2 deposits are interpreted to have accumulated subsequent to the fault displacement. The radiocarbon age of charcoal sampled from a burn horizon near the base of unfaulted unit 2 was 3530 ± 82 cal B.P. (sample UC7 in Fig. 4

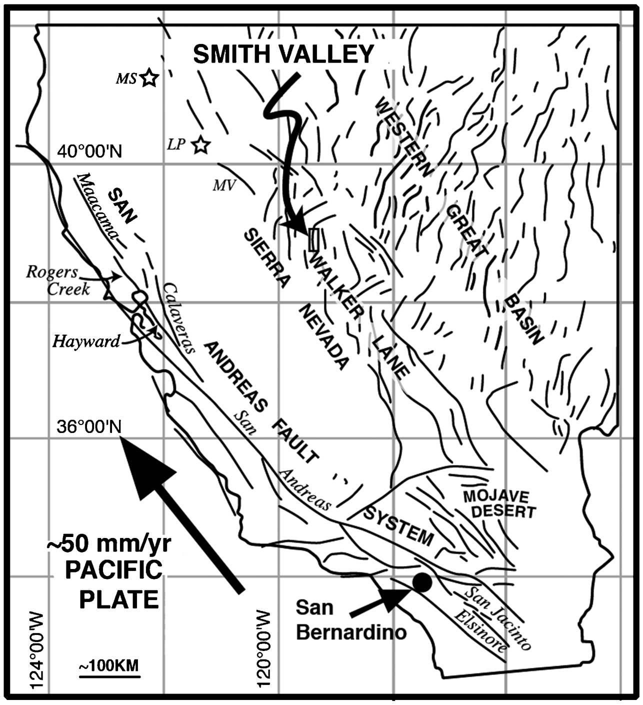

Figure 1. The small box at the end of the arrow shows the location of Smith Valley and Figure 2 in relation to major fault systems and physiographic features of the western United States. The plate-motion vector is from Demets and Dixon (1999).

and ⒺTable S1 available as an electronic supplement to this paper). A charcoal sample taken from the faulted unit 1 yielded a radiocarbon age of 5176 ± 130 cal B.P. (sample UC2 in Fig. 4 and ⒺTable S1 available as an electronic supplement to this paper). The observations indicate that the 2 most recent surface displacement occurred after 5176± 130 cal yr B.P. The location of UC7 at the base of unit 2 is reason to suggest that the last displacement was close in time to 3530 ± 82 cal B.P. The similarity of the offset 3 (thickness of colluvial wedge) observed in the trench-to-scarp height observed on the surface (3.5 m) suggests that the scarp is primarily if not completely due to a single earthquake displacement.

Artesia Road Fan—Site 02

To the north of the West Walker River, the fault takes a sharp right bend. Here, an unnamed drainage is the source of the moderate sized Artesia Road fan on which scarps produced by the range-bounding fault are clearly expressed (Figs. 2 and 5). In Figure 6, the surficial geology, scarp locations, vertical separation profiles, and annotated sample localities are placed on a 2-m contour base map. The fan is composed of granitic gravel. Surface characteristics of color and morphology allow division of the fan surface into three units of progressively greater age. The youngest of these (Qy) is a small fan cone composed of angular cobble and boulder gravel and the modern drainage channel from which it emanates. The drainage channel and fan cone of Qy, respectively,

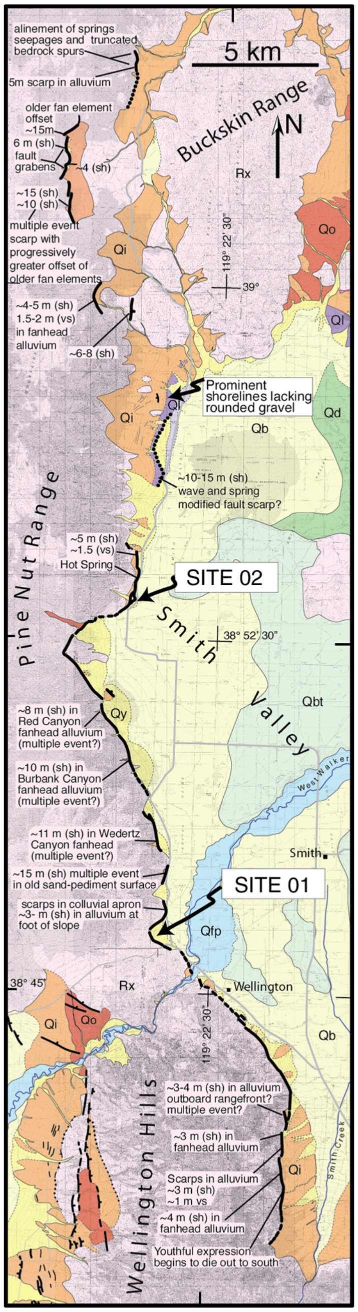

Figure 2. This schematic Quaternary surficial map shows active fault trace, measurements of scarp heights where they were measured in young alluvium, and location of sites 01 and 02. Qy, Qi, and Qi are relatively young, intermediate, and older alluvial fan surfaces, respectively, and Qb and Qbt are basin fill and basin fill terrace deposits, respectively. Qfp is the floodplain of the West Walker river, Qd are dunes, and Ql are lacustrine or wave-modified alluvial deposits. Older rocks are undifferentiated and labeled Rx. Measurements of scarp height and vertical separation are labeled sh and vs, respectively. The study described here at site 02 demonstrates that the rangefront has experienced multiple Late Pleistocene displacements. A number of scarps in alluvium along the rangefront are marked with a query and suggested to also represent multiple-event scarps based on their relatively greater size than the single-event scarp documented at site 01. The map is constructed on 7.5′ topographic sheets of the USGS. The color version of this figure is available only in the electronic edition.

Figure 3. West view over the location of the site 01 trench. The color version of this figure is available only in the electronic edition.

cut and rest upon the intermediate age unit Qi. The unit Qi surface is characterized by a bright white tone resulting from generally unweathered and poorly sorted angular and subangular boulders in a poorly sorted sand-to-cobble matrix. Debris-flow levees and channels are interspersed within the bar and swale topography of the Qi surface. Qo, the oldest surface, is distinguished from Qi by its red tone, smooth surface, and a lesser frequency, smaller size, and common absence of cobbles and boulders. Measurements of the cumulative vertical separation across the scarps range from about 7–10 m and 16–22 m across the younger Qi and older Qo surfaces, respectively (Fig. 6). For simplicity of discussion, the variability in the estimates of vertical separations measured across the scarps are ignored, and offsets of the Qi and Qo surfaces are taken herein to be 10 and 20 m, respectively.

Age estimates of the fan surface, and thus limits on the rate of fault displacement, result from (1) tephrochronology of lacustrine beds on which the fan has developed and (2) the calculated cosmogenic surface exposure ages of several boulders on the fan surface.

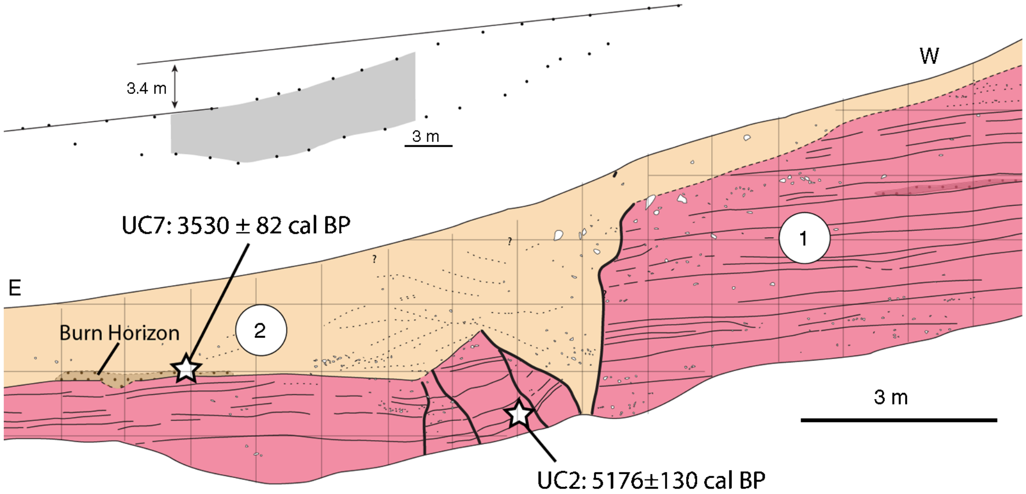

Figure 4. (Lower) Log of exposure and location and age of radiocarbon samples at site 01. See text for discussion. (Upper) Points sho 10 survey of the trench bottom and scarp profile along the south wall of trench. Shaded area marks the extent of mapped exposure shown below. 11 Vertical separation in profile is within measurement the same as vertical offset of top of unit 1. The observation is used to suggest that the surface scarp here is due to the single and most recent earthquake displacement. The color version of this figure is available only in the electronic edition.

Figure 5. Southwest view over the site 02 scarps that cut the Artesia Road fan. The white stars and circle show locations of tephra and rocks (multiple) sampled for cosmogenic analysis and discussed in text. The coordinates, labels, and map location of the sampled rocks are 12 further detailed in Figure 6. The color version of this figure is available only in the electronic edition.

Tephrochronology

The sample SGW-SV1-2008 was sampled along a road cut exposing fine-grained gray lacustrine sediments below the alluvial Qo surface (Fig. 6). Electron microprobe (EM), chemical, and statistical analyses was performed by the United States Geological Survey (USGS) Tephrochronology 4 Project in Menlo Park, California. EMA methodogy is described in Sarna-Wojcicki *et al.* (1984). Data evaluation methods are based on the similarity coefficient of Borchardt (1974) and Borchardt *et al.* (1972). For a more complete and detailed description of tephrochronologic methods, see Sarna-Wojcicki (2000) and Sarna-Wojcicki and Davis (1991). Analytical results show that sample SGW-SV1-2008 closely matches (~0.96 similarity coefficient) a Pleistocene tephra (~75–80 k.y., correlated age range) recovered from Owens Lake in southeast California. The correlated age range is based on a sedimentation-rate curve presented by Bischoff 5 *et al.* (1997; E. Wan, USGS, personal comm.).

6 Stauffer (2003) reports the analysis of a tephra (sample 99AL617-154 from Stauffer, 2003) from lacustrine sediments across the valley to the east, interpreted to have been deposited by the same lake. Analyses also show that 99AL617-154 matches well (0.95–0.97 similarity coefficient) with several samples from cores in Walker Lake. The Walker Lake core 7 samples have estimated ages of 80–60 k.y. ago (during MOI Stage 4) based on sedimentation-rate estimates for Walker Lake (Stauffer, 2003, reporting 2003 personal communication of Sarna-Wojcicki, USGS). AL98-51A is another MOIS 4 (70–60 k.y.) tephra layer within the same lacustrine beds, shown at the south end of the map area of Figure 6 (collector: Stauffer, 2003). Unfortunately, the geochemical fingerprint of AL98-51A does not compare as well as the other samples. Nevertheless, the synthesized tephrochronology places the development of the fan subsequent to about 80,000–60,000 yr ago.

Cosmogenic Analysis

Several granitic boulders were sampled from the older Qo fan surface with the aim of determining the length of time each has been exposed to cosmogenic radiation at the Earth's surface. Estimating the age entails measurement of the quantity of the isotope ^{10}Be that has accumulated in the quartz fraction of the rock. A review of the theory, method, and various applications of the method are found in Gosse and Phillips (2001). The geographic and production rate parameters, further references to the specifics of the methodology used for calculating the exposure ages of the boulders, and field photos of the particular samples are provided in Ⓔ Table S2, available as an electronic supplement to this paper. The three boulders sampled were among the largest on the Qo fan surface and situated between scarps that cut the fan surface (Fig. 6). The boulders sit 25 to 60 cm above the fan surface and are labeled CWL-2, CWL-3, and CWL-4 in Figure 6.

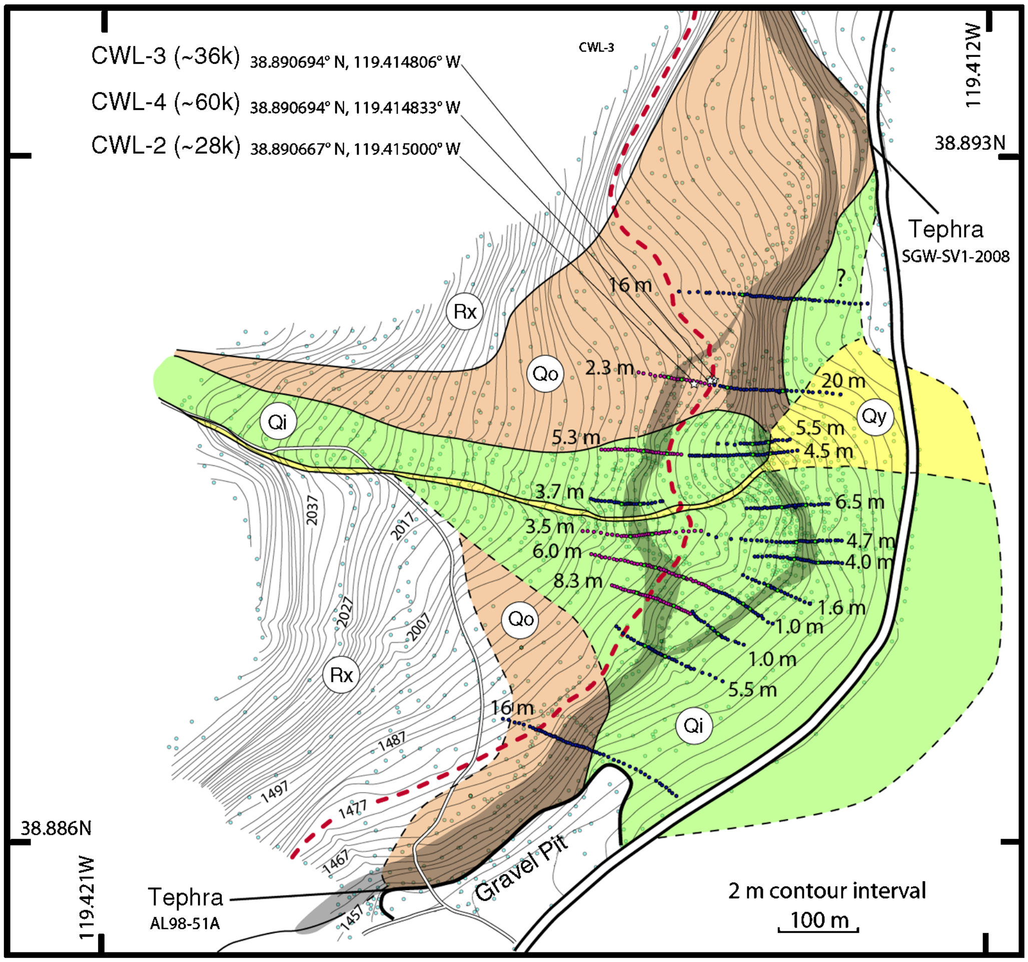

Figure 6. Quaternary surficial geologic map on 2-m contour base of Artesia Road fan (site 02). The control points are shown by light and dark dots. The 1477-m contour is relatively thicker and dashed. The fault scarps are shaded. Vertical separation across scarps determined from the densely aligned control point profiles is annotated. Stars show the location of rocks sampled for cosmogenic analysis, and the location of tephras discussed in text are labeled. Qy, Qi, and Oo are alluvial fan surfaces of increasingly greater age. Older, undifferentiated rocks are labeled Rx. The color version of this figure is available only in the electronic edition.

The upper several centimeters of each was sampled for analysis. Horizon corrections were noted but negligible for each.

The exposure ages for the three samples are 28.3± 2 k.y., 36.0 ± 3 k.y., and 60.5 ± 5 k.y., respectively. Though not well grouped, the ages are younger than and, in that regard, consistent with the maximum bounding age of the fan suggested by the tephra analysis for the underlying lacustrine beds. Likewise, the younger ages suggest that the three cosmogenic samples are not contaminated by inheritance of an older exposure age prior to deposition on the fan. The lesser size and frequency of granitic boulders on the Qo surface as compared to the Qi surface suggest that spalling and grussification of the granitic clasts that compose the surface are significant surface processes here, and in that sense, variations in the degree of spalling of the individual boulders may be responsible for the spread in the exposure ages obtained for the three samples. As well, the difference in ages may reflect that the boulders were indeed initially exposed to the Earth's surface at different times. With these observations in mind, it is assumed here that the oldest of the three cosmogenic ages (60.5 ± 5 k.y.) represents a minimum age for the abandonment of the Qo surface.

Fault-Slip Rate

Estimates of the maximum and minimum bounds on the vertical component of fault-slip rate are followed here by discussion of observations and uncertainties pertaining to the bounding estimates. A minimum bound of 0.125 mm/yr results from dividing the minimum offset of the Qi surface (~10 m) by the 80 k.y. age of the lacustrine sediments that sit below the Qo fan surface. A maximum bound of 0.33 mm/yr arises from taking the oldest of the cosmogenic exposure ages (~60 k) determined for rocks on the Qo surface and dividing by the ~20 m scarp height recorded on the Qo surface. Attempts to determine the slip rate with greater precision are hindered by uncertainties associated with the high stand of the ancient lake that deposited the tephra-bearing sediments and the genesis of the rocks sampled for cosmogenic analysis. These uncertainties and reasons for assuming the respective values of offset and age when determining the preceding bounds on vertical slip rate are outlined in the ensuing paragraphs of this section.

The highstand of the now-dry Lake Wellington reached a highstand of 1477 m (Mifflen and Wheat, 1979; Reheis, 1999; Stauffer, 2003). The 1477-m contour is relatively thicker and dashed in Figure 6 and extends along and above the crest of the ~20 m scarp in the older Qo fan remnant. Though no lacustrine deposits are observed on the surface, some chance exists that the ~20 m scarp in Qo is in part due to wave action at the ancient Lake's edge while the lake-level was below the highest stand, in which case the ~20 m scarp may be wave-modified, not entirely of tectonic origin, and thus, a maximum bound on the amount of slip recorded by the Qo fan surface.

The location of the rocks sampled for cosmogenic analysis also suggests that they were exposed due to fault degradation after some offset had already occurred. If so, (1) the ~20-m scarp is a maximum bound on the amount of displacement since abandonment of the Qo surface, (2) the cosmogenic exposure ages of the sampled rocks are minimum estimates of the age of the fan surface, and (3) the ~10 m registered on the Qi surface likely records the minimum amount of offset since abandonment of the Qo surface.

Large boulders and clasts are only present above the scarps along the easternmost ~30 m of the Qo surface. It is for this reason samples CWL-2, CWL-3, and CWL-4 were sampled where they are. The boulder concentration is also loosely correlated with the highstand elevation contour of 1477 m. It is difficult to discount the possibility that the concentration of boulders is the result of wave action over the scarp crest at the lake's edge. The lack of rounded gravels indicating wave action on the fan would, at first, appear to argue against the idea, but elsewhere around the basin there are prominent strand or beach lines of the lake highstand that display only angular and subangular gravel and boulders (see location north of site 02 in Fig. 2). If wave action is responsible for exposure of the sampled boulders, the exposure of the boulders sampled may also postdate the emplacement of the older Qo fan element, and it follows again that the exposure ages would be a minimum estimate of the age of the Qo fan surface.

Summary and Conclusions

Interpretation of an exposure afforded by excavation of a trench across the range-bounding fault of the Pine Nut mountains places the most recent surface-rupture earthquake after 5176 ± 130 cal B.P. and suggest it was close in time to 3530 ± 82 cal B.P. Utilization of tephrochonologic and cosmogenic analyses and mapping of fault scarps across the Artesia Road fan place the Late Pleistocene vertical slip rate of the fault at between about 0.125 mm/yr and 0.33 mm/yr. Assuming the underlying fault dips at some angle θ, the 8 fault-slip rate would be greater by $1/\cos(\theta)$ and the horizontal extension rate less by a factor of $\tan(\theta)$. These first quantified estimates of fault-slip rate and paleoearthquake history in Smith Valley may ultimately be of use in quantifying seismic hazards and understanding the regional relationship of fault-slip rates measured by geology to those now being recorded geodetically.

Data and Resources

All data used in this paper was collected during the course of study or came from published sources listed in the references.

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