[PS]Evidence of a Developing Cross Valley Fault Based on Fault Scarp Morphology in the Eureka Valley, California, U.S.A.*

Ernest Nunez[1], Anthony Zepeda[1], Nathan Montoy[1], Tyanna Schlom[1], and Jeffrey Knott[1]

Search and Discovery Article #50612 (2012)**
Posted June 11, 2012

*Adapted from poster presentation given at AAPG 2012 Annual Convention and Exhibition, Long Beach, California, 22-25 April 2012

[1]Geological Sciences, CSU Fullerton, Fullerton, CA (ehnunez@csu.fullerton.edu)

Abstract

Eureka Valley, CA, NW Death Valley National Park, is one of a series of valleys formed by oblique extension within the Eastern California shear zone and Walker Lane belt. In Eureka Valley, extension is accommodated by the normal-oblique, north-south trending Eureka Valley fault zone (EVFZ) that bounds the valley's east side at the foot of the Last Chance Range. An Mw 6.1 earthquake on May 17, 1993 is attributed to a northeast-southwest-trending trace of EVFZ located in the west-central portion of the valley. The earthquake produced ground deformation best detected by remote sensing with only minor ground cracks observed after the earthquake. The minor ground rupture is in stark contrast to the prominent fault scarps found along valley-bounding fault on the east side. Here we present measured fault scarp profiles offsetting Quaternary alluvial-fan deposits along traces of the EVFZ at the foot of the Last Chance Range. The displacements and maximum fault scarp slope angles are consistent with Mw 7-7.5 events. In the south, fault scarps offset older ~70 ka alluvial-fan deposits. In the north, fault scarps trend parallel to the 1993 aftershock pattern and offset ~30 ka alluvial-fan deposits with scarp angles suggesting events <2 ka. Based on the age differences of offset fan deposits, we infer that the southern EVFZ has been inactive for >30 ka. In contrast, the northern EVFZ has produced at least two earthquakes in the last 30 ka. The parallel trends of the northern scarps and the 1993 event suggest that a cross-valley fault is developing in Eureka Valley. The development of a cross-valley fault is consistent with clay models and field observations of a basin in the late extension phase. Cross-valley faults are known barriers and facilitators of oil migration; however, in the case of Eureka Valley, gravity data suggests that the basin sediments in the north are thicker than the south - suggesting that cross-valley faulting has persisted for a sufficient time to influence depocenter location.

Selected References

Asad, A.M., S.K. Pullammanappallil, A. Anooshehpoor, and J.N. Louie, J.N., 1999, Inversion of travel-time data for earthquake locations and three-dimensional velocity structure in the Eureka Valley area, eastern California: Seismological Society of America Bulletin, v. 89/3, p. 796-810.

Bucknam, R.C., and R.E. Anderson, 1979, Estimation of fault-scarp ages from a scarp-height-slope-angle relationship: Geology, v. 7/1, p. 11-14.

Hunt, C.B., and D.R. Mabey, 1966, Stratigraphy and structure, Death Valley, Californi: USGS Professional Paper #494-A, p. A1-A165.

Knott, J.R., A.M. Sarna-Wojcicki, M.N. Machette, and R.E. Klinger, 2005, Upper Neogene stratigraphy and tectonics of Death Valley – a review, *in* J.P. Calzia, (ed.), Fifty years of Death Valley research; a volume in honor of Lauren A. Wright and Bennie Troxel: EarthScience Reviews, v. 73/1-4, p. 245-270.

McClay, K., and T. Dooley, 1995, Analogue models of pull-apart basins: Geology, v. 23/8, p. 711-714.

Nash, D.B., 1984, Morphologic dating of fluvial terrace scarps and fault scarps near West Yellowstone, Montana: GSA Bulletin, v. 95/12, p. 1413-1424.

Turko, J.M., and L.K. Knuepfer, 1991, Late Quaternary fault segmentation from analysis of scarp morphology: Geology, v. 19/7, p. 718-721.

Wallace, R.E., 1977, Profiles and ages of young fault scarps, north-central Nevada: GSA Bulletin, v. 88, p. 1267-1281.

Wells, D.L., and K.J. Coppersmith, 1994, New empirical relationships among magnitude, rupture length, rupture area and surface displacement: Seismological Society of America Bulletin, v. 84/4, p. 974-1002.

Zhang, P., B.C. Burchfiel, S. Chen, and Q. Deng, 1989, Extinction of pull-apart basins: Geology, v. 17/9, p. 814-817.

EVIDENCE OF A DEVELOPING CROSS VALLEY FAULT BASED ON FAULT SCARP MORPHOLOGY IN THE EUREKA VALLEY, CA, U.S.A.

Ernest Nunez, Anthony Zepeda, Nathan Montoy, Tyanna Schlom and Jeffrey Knott
Department of Geological Sciences, California State University, Fullerton, Box 6850, Fullerton, CA 92834

ABSTRACT

Eureka Valley, CA, in northwestern Death Valley National Park, is one of a series of valleys formed by oblique extension within the Eastern California shear zone and Walker Lane belt. In Eureka Valley, extension is accommodated by the normal-oblique, north-south trending Eureka Valley fault zone (EVFZ) that bounds the valley's east side at the foot of the Last Chance Range. A M_w 6.1 earthquake on May 17, 1993 is attributed to a northeast-southwest-trending trace of the EVFZ located in the west-central portion of the valley. The earthquake produced ground deformation best detected by remote sensing with only minor ground cracks observed after the earthquake. The minor ground rupture is in stark contrast to the prominent fault scarps found along the valley-bounding fault on the east side. Here we present measured fault scarp profiles offsetting Quaternary alluvial-fan deposits along the EVFZ at the foot of the Last Chance Range. Fault scarp height and slope angle are used to estimate the earthquake magnitude and age. The parallel trends of the northern scarps and the 1993 event suggest that a cross-valley fault is developing in Eureka Valley. The development of a cross-valley fault is consistent with clay models and field observations of a basin in the late extension phase.

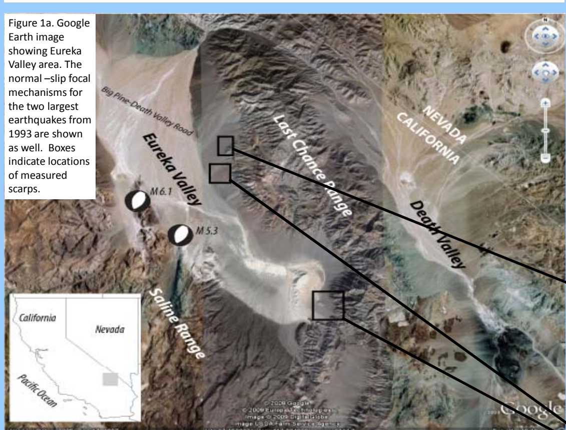


Figure 1a. Google Earth image showing Eureka Valley area. The normal –slip focal mechanisms for the two largest earthquakes from 1993 are shown as well. Boxes indicate locations of measured scarps.

INTRODUCTION

The M_w 6.1 earthquake in 1993 in Eureka Valley indicated that faults within the north-south trending Eureka Valley fault zone (EVFZ) are active fault (Asad et al., 1999). The EVFZ is located ~17km southwest of the California/Nevada Border in northwest corner of Death Valley National Park. However, the Quaternary slip rate for the EVFZ is relatively unknown and the last activity on the fault is classified only as Pleistocene.

The epicenter of the 1993 Eureka Valley earthquake was near the west side of Eureka Valley (Figure 1a) and did not produce ground rupture (S. Hecker, USGS, pers. comm., 2010). The epicenter and the largest aftershock are located along prominent northeast-trending ridges that extend into the valley playa. The location of the epicenters is surprising because prominent fault scarps are visible along the east side of the valley at the base of the Last Chance Range (Figure 1b) and regional geologic mapping shows no Quaternary faulting.

In this study, we examine fault scarps along the EVFZ at the foot of the Last Chance Range that offset Quaternary alluvial-fan deposits. We measured the maximum angle and scarp height at several locations to estimate the earthquake age and magnitude using the methods of Bucknam and Anderson (1979) and Wells and Coppersmith (1994).

METHODS

Scarp Morphology

Scarp morphology may be a useful indicator of earthquake event age in a particular region . Immediately following a scarp forming earthquake, scarps begin weathering and erosion (Wallace, 1977). The scarps follow a model of hillslope evolution over time, where the base rises and the crest lowers (Turko and Knuepfer, 1991). By estimating the slope height and angle (Figure 2a), one can compare the scarp slope to dated features nearby, providing a relative age of the scarp (Bucknam and Anderson, 1979). Scarps in Eureka Valley were surveyed using a laser theodolite (Figure 2b).

Alluvial fan morphology

Determining the ages of alluvial-fan surfaces may help constrain earthquake age as well. In the Death Valley region, four prominent alluvial-fan surfaces are distinguishable by their surface morphology (Hunt and Mabey, 1966; Knott et al, 2005) (Table 1).

ALLUVIAL FAN UNIT	SURFACE MORPHOLOGY	AGE
Qg4	Active Channel	Holocene
Qg3	Subdued bar and swale; moderate varnish	12,000-30,000 yrs
Qg2	No bar and swale; strong varnish and desert pavement	60,000-70,000 yrs

Figure 2a

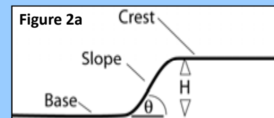


Figure 2b

RESULTS

Fault scarps in northern Eureka Valley are different from north to south. North of the Big Pine Road (Figure 1a & 1b) at scarp 1, the Qg3 alluvial fan is offset 0.7 m vertically and 3.2 m right-laterally (Fig. 3a) with a maximum scarp angle of 20°. The maximum slope angle for scarp 3 is 40° (Fig. 3b) and the Qg3 is offset 1.5 m.

South of the Big Pine Road, in central Eureka Valley, the Qg3 alluvial fan is offset 1.1-1.2 m with a maximum slope angle of 34° (Fig. 3c). A second scarp here offsets the Qg2 alluvial fan a minimum of 7 m with a maximum slope angle of 24°.

In southern Eureka Valley, the Qg3 alluvial fan is not offset; however, the older Qg2 fan is offset by two events (Fig. 3d). The upper scarp is 5.5 m and the lower scarp offsets the Qg2 fan by 4 m. The maximum scarp angles are 40° and 35°, respectively.

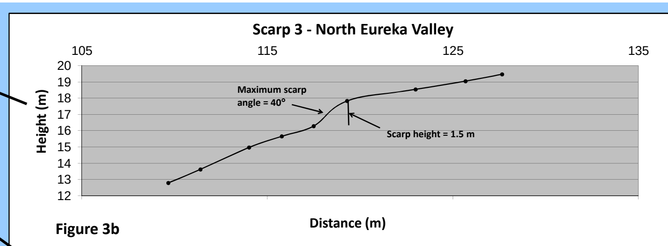


Figure 3b

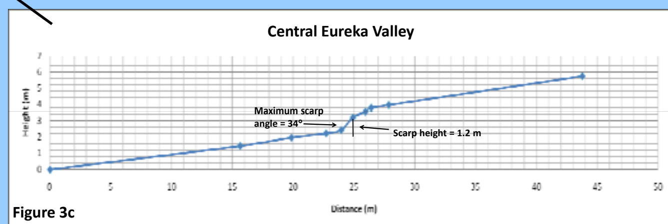


Figure 3c

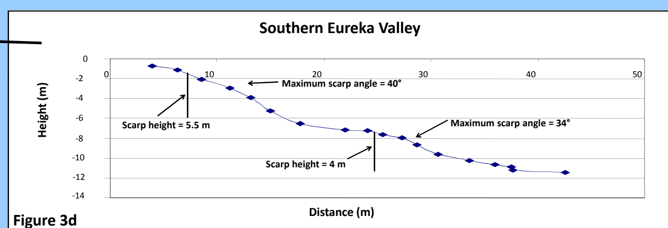


Figure 3d

Fig. 3a Scarp 1 North of Big Pine Road

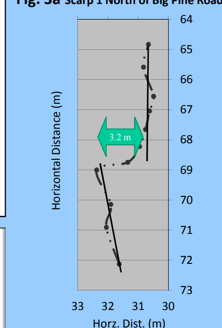


FIGURE 3a. Survey of right-lateral offset of scarp profile 2 north of the Big Pine Road. The photograph below shows the left two individuals standing on the offset channel thalweg whereas the right two individuals are standing on the crest of an offset ridge across the Eureka Valley Fault Zone

DISCUSSION

Eureka Valley is an extensional half graben with the normal fault along the east side and a general northwest-southeast extension. According to McClay and Dooley (1995) pull-apart basins begin with shearing accommodated along the basin margins (Figure 5). As shearing continues dextral strike-slip faults develop that accumulate significant extensional displacement as an oblique-striking cross-basin fault zone that links the two principal displacement zones (McClay and Dooley (1995). Zhang et al. (1989) described the development of this cross valley fault as an indication of extinction of the pull-apart basin. In the case of Eureka Valley, the juvenile nature of the cross-valley fault suggests the initial phase of basin extraction (Zhang et al., 1989). In petroleum bearing systems, such a cross-valley fault might separate reservoir from source rock and generate two separate production zones.

The scarps in northern and central Eureka Valley may be interpreted at 1 or 2 earthquakes due to the style and amount of offset (Figure 6a). The age of the earthquake is less than 2 ka according to Bucknam and Anderson (1978).

Scarps in southern Eureka Valley are clearly a separate event, based on the fact that they do not offset the younger Qg3 alluvial fans. This event may have ruptured north into central Eureka Valley with a likely age of 7-14.5 ka (Figure 6a).

Several of the scarps have slope angles greater than the angle repose, which suggests that soil development impacts cohesion.

Figure 5

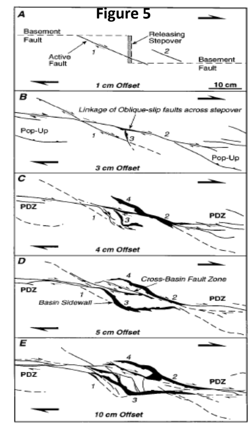
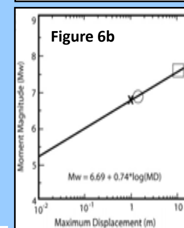


Figure 2. Plan view of progressive evolution of experiment W38. A: 1 cm offset. B: 3 cm offset. C: 4 cm offset. D: 5 cm offset. E: 10 cm offset. Dashed lines indicate inactive fault strands, solid lines indicate active fault strands. Pull-apart basin bounding faults are labeled 1–4. PDZ is principal displacement zone. From McClay and Dooley (1995).

Figure 6b



The maximum displacements also suggest at least two events. The 7-14.5 ka event estimated at Mw=7.5 and the <2 ka event Mw=6.7 (Figure 6b).

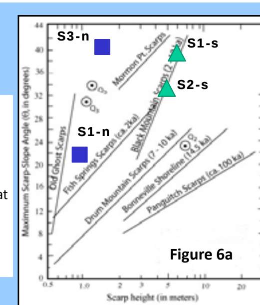


Figure 6a

CONCLUSIONS

1. Eureka Valley is in the initial stages of extinction with a developing cross valley fault (McClay and Dooley, 1995).
2. Development of the cross valley fault corresponds with late stage development and basin extinction (Zhang et. al. 1988)
3. These results show that in well-developed extensional basins and the petroleum reservoirs in them may be subdivided by late stage cross valley faults.
4. Fault scarp angles and offsets suggest at least two earthquakes in Eureka Valley with the southern scarps inactive in the last 12-30 ka.

ACKNOWLEDGEMENTS

This study is an undergraduate research project at CSUF. This study was supported by grants from NSF:HRD – 0802628 Louis Stokes Alliance for Minority Participation (LSAMP) , Petroleum Research Fund and CSU Fullerton. Meeting travel supported by SEPM and AAPG. Special thanks to field assistants Kyle McCarty, David Manoukian, and Daniel Whitmer.

REFERENCES

Asad, A.M., Pullammanappallil, S.K., Anooshehpoor, A., and J. N. Louie, J.N. (1999). Inversion of travel-time data for earthquake locations and three-dimensional velocity structure in the Eureka Valley area, eastern California. *Bulletin of the Seismological Society of America*, v. 89, no. 3, p. 796-810.
Bucknam, R.C. and Anderson, R. E. (1979). Estimation of fault-scarp ages from a scarp-height-slope-angle relationship. Geology, v. 7, p. 11-14.
Hunt, C.B. and Mabey, D.R. (1966). Stratigraphy and structure Death Valley, California. United States Geological Survey Professional Paper, 494-A.
Knott, J.R., Sarna-Wojcicki, A.M., Machette, M.N., Klinger, R.E., (2005). Upper Neogene stratigraphy and tectonics of Death Valley – a review. Earth-Science Reviews 73, p. 245-270.
McClay, K, and Dooley, T. (1995). Analogue models of pull-apart basins. Geology, v. 23, p. 711-714.
Nash, D.B. (1984). Morhpologic dating of fluvial terrace scarps and fault scarps near West Yellowstone, Montana. Geological Society of America Bulletin, v. 95, p. 1413-1424.
Schlom, T., (2010). Earthquake Magnitude and Recurrence from Scarp Morphology, Eureka Valley Fault Zone, Eastern California. CSU, Fullerton Undergraduate Thesis, p. 10.
Turko, J.M., Knuepfer, L.K. (1991). Late Quaternary fault segmentation from analysis of scarp morphology. Geology, v. 19, p. 718-721.
Wallace, R.E. (1977). Profiles and ages of young fault scarps, north-central Nevada. Geological Society of America Bulletin. v. 88, p.1267-1281.
Wells, D.L. and Coppersmith, K.J. (1994). New empirical relationships among magnitude, rupture length, rupture area and surface displacement. Bulletin of the Seismological Society of America, v. 84, n. 4, p. 974-1002.
Zepeda, A., (2011). Fault Scarp Dating and Moment Magnitude along the Northern Eureka Valley Fault Zone, Eastern California. CSU, Fullerton Undergraduate Thesis, p. 8.
Zhang, P., et al. (1989). Extinction of pull-apart basins. Geology, v. 17, p. 814-817.