

Determining The Timing And Offset Of Secondary Normal Faults In The Kit Fox Hills Adjacent The Northern Death Valley Fault Zone, Death Valley, California

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Abstract

The Kit Fox Hills of Death Valley National Park, California (Figure 1) are composed of late Tertiary and Quaternary sediments uplifted by folding and faulting along the right-lateral Northern Death Valley Fault Zone (NDVZF). Along the NDVZF are arcuate normal faults that extend away from the fault at ~45 degree angle, and then parallel the fault zone. In this paper I determine the offset and estimated age of these normal faults by offset relations and morphology. Three fault scarp faces were examined and their profiles measured. Two of the three were found to have a maximum angle less than the angle of repose and thus amenable to the Bucknam and Anderson (1979) method. Scarp 1 was found to be between 6-8 ka and scarp 2 plotted in the range of 800 years – 1.5 ka. The third fault scarp has a 62 degree scarp face indicating a relatively young scarp or high cohesion, carbonate-cemented soils. With too many variables attached to scarp 3, finding a relative age remains undetermined. The differing ages of the scarps (6-8 ka and 0.8-1.5 ka) shows that more than one earthquake formed these secondary faults and that these types of faults areas have a ground-rupture hazard for buildings near strike-slip faults.

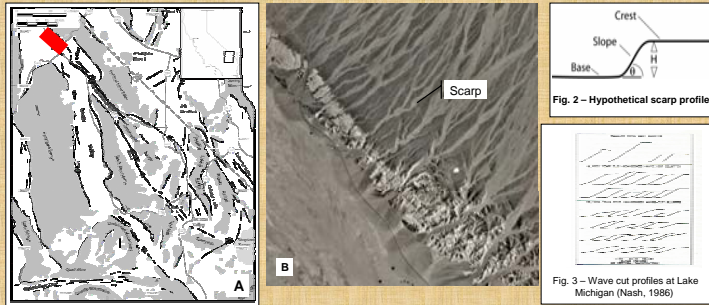


Fig. 1 – (A) Map showing geographic features and major faults. Red box indicates area of photograph (B) Photograph of northern Kit Fox Hills. Light uplifted sediments are at bottom. Scarps offset alluvium.

Theory

Fault scarp morphology dating is most commonly applied to normal faults (Wallace, 1977). According to Wallace (1977), fault scarps consist of three basic sections: crest, slope and base (Fig. 2). The crest and the base are remnants of the originally continuous deposit that was displaced (H) during the earthquake. The slope is the critical aspect used for age determination. Slope angles decrease with time with slopes >55° (<1,000 years) being free faces (Wallace, 1977).

Degradation is the process where the hill slope ultimately erodes into a flat plain. The slow rate of natural hill slope degradation (hundreds to thousands of years) makes observation of this process difficult. However, the rate of degradation can be inferred by comparing the slope profile of different-aged hill slopes formed by the same process. For example, Nash (1986) examined wave-cut bluffs along the Lake Michigan shoreline whose ages were determined by radiocarbon dating (Fig. 3). Profiles of the same age degraded to the same shape.

The original shape of a wave cut bluff is similar to normal fault scarps. Therefore, if a profile of known age is found in the region, then this profile morphology may be used to determine the age of other fault scarps in that region. Bucknam and Anderson (1979) used the degradation of radiocarbon dated wave cut bluffs from Lake Bonneville to approximate the ages of fault scarps in the Basin and Range. Based on this data they concluded that:

- (1) the slope angle of the scarp is proportional to the logarithm of the scarp height and,
- (2) the slope angle decreases with the estimated age of scarps with a given height.

Thus, by measuring the scarp height and the slope angle (Fig. 2) the age of the earthquake or wave cut scarp may be determined. Using the wave cuts of known age from the Lake Bonneville shoreline as a benchmark, Bucknam and Anderson (1979) then plotted the height versus maximum slope angle for several fault scarps in the Basin and Range and determined estimated age range for these fault scarps (Fig. 4; from Klinger, 2001). Considering the relatively consistent climate of the Basin and Range, this graph may be used to determine an age range normal fault scarps. Machette and others(2001) and Klinger (2001) used this method to determine the ages of fault scarps in other areas of Death Valley.

Potential Errors

Degradation rate: More humid regions will degrade faster than more arid regions.

Lithology: More resistant lithologies degrade slower (e.g., cemented sandstone versus unconsolidated alluvium).

Pedogenesis: Cementation by pedogenesis makes scarps more resistant to erosion (Prokop, 1983).

RESULTS AND INTERPRETATION

GEOLOGIC MAP: Four Quaternary alluvial-fan units are known in Death Valley (Hunt and Mabey, 1966; Klinger, 2001). Q₁ is the oldest alluvium with an estimated age of >60 ka (Klinger, 2001) and is not exposed within the study area. Q₂, the second oldest alluvial-fan deposit (Fig. 4), has an estimated age of 60-30 ka (Klinger, 2001) and moderate desert pavement and varnish. The clasts are cobble to pebbles in size and the surface is several meters above the active channel. Q₂ caps the Kit Fox Hills in the study area. Q₃ has a bar and swale morphology, moderate desert varnish and pavement in topographic lows. Klinger (2001) estimates an age 12-2 ka for deposits with Q₃ morphology. Q₄ is the active channels of loose unconsolidated gravels (Fig. 4).

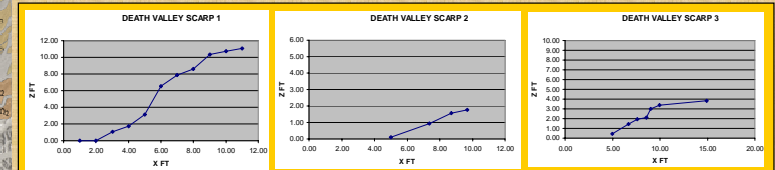
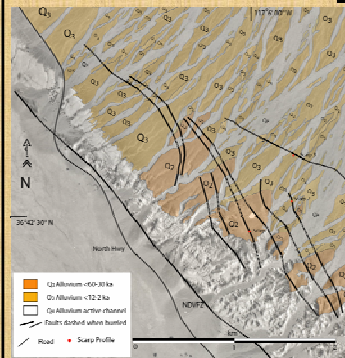
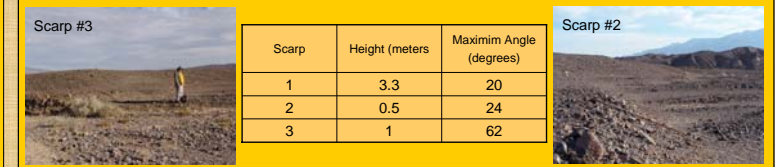


Fig. 5 – Profiles measured with Brunton compass and stadia rod (above). Data is in feet for comparison to earlier studies. Photographs of scarps measured (below). Note the bar and swale topography of the base of scarp 2.



AGE OF FAULTING: Three fault scarps were profiled (Fig. 5). The location of these scarps are identified on the geologic map.

Scarp 1 offsets Q₂ and Q₃ alluvium and therefore must be <12-2 ka. Scarp 1 Scarp Height vs Maximum Slope Angle plots near the 8-5 ka Drum Mountains scarp (Fig. 6) (Bucknam and Anderson, 1979). No offset surface was found on both the upthrown and downthrown side of the scarp as it offset Q₃.

Scarp 2 offsets parts of Q₂ and Q₃ fans indicating the scarp age must be <12-2 ka (Fig. 6). The Scarp Height vs. Maximum Slope Angle plots near the 600-500 year old Old Ghost scarps found to the south in the transition between the NDVZF and the Black Mountains fault zone (Machette and others, 2001).

Mapping shows that scarp 3 offsets Q₂ and Q₃ and does not offset the Q₄. The maximum slope angle is out of the range found by Bucknam and Anderson (1979). The steep scarp angle could indicate either a young (<200 years old) scarp or the presence of a high cohesion, carbonate-cemented soil, which would increase resistance to erosion (Fig. 6). The lack of a clear cross cutting relation with the younger Q₄ deposits suggests that the high slope angle is probably due to carbonate-cemented soils. As a result, the age of scarp 3 is undeterminable using morphological methods.

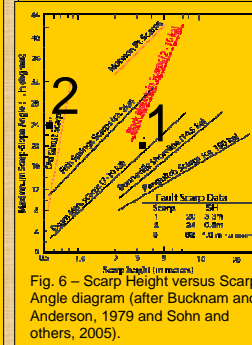


Fig. 6 – Scarp Height versus Scarp Angle diagram (after Bucknam and Anderson, 1979 and Sohn and others, 2005).

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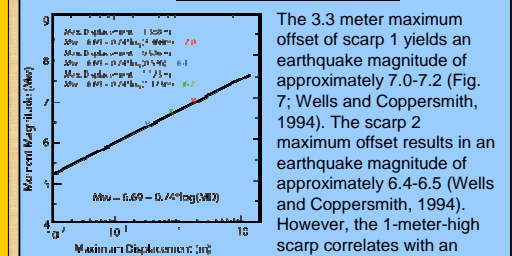


Fig. 7 – Correlation diagram from Wells and Coppersmith (1994).

The 3.3 meter maximum offset of scarp 1 yields an earthquake magnitude of approximately 7.0-7.2 (Fig. 7; Wells and Coppersmith, 1994). The scarp 2 maximum offset results in an earthquake magnitude of approximately 6.4-6.5 (Wells and Coppersmith, 1994). However, the 1-meter-high scarp correlates with an earthquake magnitude of approximately 6.7-6.8.

CONCLUSIONS

The age of last known movement on the NDVZF is approximately 25-30 ka (Brogan and others, 1991; Machette and others, 2001). Based on offset relations and scarp morphology, the three normal scarps have likely been produced during the last 10,000 years. If these faults move in conjunction with the NDVZF, then the NDVZF has post-10 ka slip. From the varying morphology and scarp ages, I also conclude each scarp was formed by separate individual events at different times. Offsets, even on these secondary faults, suggest earthquakes with magnitudes (M_w) from 6.5 to 7.0. These scarps define a ground-rupture hazard zone that extends nearly 1 km away from the main NDVZF trace. This amplifies the potential ground-rupture danger secondary faults present along strike-slip fault systems.

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