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Quaternary faulting and Seismic Source Characterization in the Las Vegas Metropolitan Area

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ABSTRACT

The Las Vegas, Nevada metropolitan area, with a population of ~1.3 million people, is traversed by Pleistocene-Holocene faults. The high estimated risk, significant population and ongoing construction indicate that it is critical to better constrain the seismic rupture hazard, fault parameters (e.g., recurrence interval, magnitude of seismic and coseismic offset, age of recent ruptures) and seismic source characteristics while opportunities are still available to impact construction methods, urban planning, and emergency preparedness planning. Our established connections with the Nevada Earthquake Safety Council, Clark County building division and the Nevada Bureau of Mines and Geology provide conduits for us to provide this information to local and state authorities and the public.

No detailed published studies including geophysics and geochronology of the young faults traversing Las Vegas exist. We performed a detailed mapping and geochronologic study of one of the faults in the Las Vegas fault system, the Eglington fault (EF) as well as detailed mapping and geophysical study of the newly defined Ithaca Avenue fault. We used the geology of Las Vegas basin, seismic geophysical methods, structural geology, and paleoseismology to make the project as comprehensive as possible. Products include a detailed fault map and subsurface geophysical data as well as data input into local and national databases and a scientific journal publication (in preparation).

INTRODUCTION

We studied two faults: (1) The Eglington fault (USGS Fault and Fold Database # 1733) is part of the Las Vegas Valley fault system, but has been separated out because it appears to have a higher rate of activity than most of the other faults in the system. The Eglington fault is entirely located within Las Vegas Valley and poses a distinct earthquake hazard to the northern part of that basin, especially the cities of North Las Vegas and Summerlin. (2) The Ithaca Road fault, which is farther south in the Valley and poses a distinct hazard to much of the basin. The Ithaca Road fault formed part of the M.S. thesis project for Willy Rittase at UNLV.

Eglington Fault

Location and Length

Geomorphic Expression

The Eglington fault has a spectacular expression in late Quaternary surfaces of Las Vegas Valley creating a large (25 m high) monoclinal warp isolating Gilcrease Flat from the downthrown side (Stewart Flat). Drainages have incised into the warp and for a short distance into the upper surface, but overall the warp and other features appear relatively uneroded and are easily seen on aerial photography. There are several vegetation lineaments in various locations on the warp, at least one that was proven to be a late Holocene fault by trenching studies.

Structural Description

The Eglington fault is a relatively short fault that may be truncated at its northeastern end by a northwest-striking cross-structure (Las Vegas Valley shear zone), and may be the northern part of the Decatur fault zone (Slemmons and others, 2001); the two faults are aligned, but there is a break in continuity of the surface expression between the two faults.

Earthquake History

The most-recent event along the Eglington fault (PE1) occurred in late Holocene. A charcoal sample was collected by Dr. Wanda Taylor (UNLV) from a consultant's exploratory trench of a young fault near the base of the Eglington warp (the El Campo Grande site). The sample came from a small colluvial wedge developed following the last event on that fault trace. The sample was submitted to Paleoresearch Laboratories for analysis, and 14 pieces of mesquite charcoal yielded a conventional radiocarbon date of 2,245 ±15 ybp. This date is dendro-corrected at a two-sigma level to two time periods, 2150 to 2250 cal ybp, or 2300 to 2340 cal ybp. The sample was detrital, thus it could be an older sample being worked into a younger wedge. Also this age of sample is common in Las Vegas Valley, indicating it may be part of an event (e.g., wildfire event, climatic event; Bell, 2006, pers. comm.). Taken at face value, the date indicates that a surface-rupturing earthquake on the Eglington fault occurred just prior to 2150 to 2340 ybp, or a little over 2000 years ago.

The fault exposed at the El Campo Grande site is synthetic to the Eglington fault, and may be a younger splay fault developing near the base of and cutting through the warp. Whether this surface rupture was a small event or part of a major event with additional displacement along the Eglington fault is not known.

Fault Slip Rates

Late Quaternary fault-slip-rate estimates for the Eglington fault are based principally on the offset of "Unit D", the local surficial geologic unit that is warped across the fault. The assumption is that a brittle, seismogenic fault lies below the warp a short distance below the surface, and the offset across the warp is the same as the offset below on the fault. Another assumption is that the age of this offset is also related to "Unit D", being in the later part or following of the deposition of "Unit D" because the upper parts of the unit are involved in the warping. Thus, dates from "Unit D" are used to estimate the time of offset. A radiocarbon date collected by Bell (1991) in a pipeline excavation across the Eglington warp was also used.

Unit D, its age, and the time of the offset of the warp

The first definition, description, and dating of "Unit D", a local subdivision of the fine-grained deposits of Tule Springs, was done by Haynes (1967). Unit D is made up of light gray, gray, and light brown mud deposits with discontinuous layers and inclusions of organic-rich deposits,

sands, gravels, and paludal (capillary fringe and spring fed) carbonate deposits (Haynes, 1967; Quade, 1986; Bell and others; 1998). The deposits crop out in the northern part of Las Vegas Valley and in other basins in southern Nevada. Thicknesses of Unit D are as much as 8 m (Bell and others, 1998). Unit D was formed during pluvial times in southern Nevada when the climate was much wetter based on the character of the deposits, fossil evidence of local flora, and its age (Quade, 1986).

Haynes obtained radiocarbon dates on gastropods near the middle and base of the deposit of 22,600 ±550 ^{14}C ybp (UCLA-536) and 31,300 ±2,500 ^{14}C ybp (UCLA-462), respectively (also reported in Quade, 1986). Haynes (1967) considers these dates to be about 1000 years too old considering other local gastropod-carbonized wood pairs. A carbonized wood sample near the base of the deposit was dated 25,300 ±2,500 ^{14}C ybp (UCLA-539). These dates are generally supported by more recent dating of Unit D, specifically four radiocarbon dates from the Tule Springs Park Quadrangle that range from 20 ky to 29 ky (Bell and others, 1998) and five radiocarbon dates from the Corn Springs Quadrangle that range from 25 ky to 34 ky (Bell and others, 1999). Quade (1986) estimates the age range for Unit D to be 15 ky to 30 ky (based on uncorrected radiocarbon dates and sedimentation rates). The youngest age estimate is made by Quade (1986) considering the 1000-year correction to some of Haynes's dates and making a "rough estimate" of the sedimentation rate for Unit D; Quade also constrains this younger age by observing the oldest radiocarbon dates in "Unit E", which overlies Unit D, are about 14 ky.

In 1991, John Bell and Craig dePolo of the Nevada Bureau of Mines and Geology visited a pipeline excavation across the Eglington Scarp at Centennial Parkway, in the eastern part of the scarp and found a charcoal layer in a small graben near the crest of the warp that post-dated a small offset (~30 cm on an antithetic scarp). This charcoal was sampled by Bell and gave a radiocarbon date of 18,690 ±170 ^{14}C ybp (GS-2958). This offset may be the early part of the modern phase of activity of the Eglington fault at this site.

The older radiocarbon dates of Haynes (1967) are too old to calibrate. Based on the calibration of Bell's 1991 date (18,690 ybp), these older dates might increase by about 3,000 years if they were calibrated.

Table 1 Radiocarbon dates and age estimates relevant to the Eglington warp

Reference	Radiocarbon Date (ybp)	Sample #	Calibrated Radicarbon Date[1]
Haynes (1967)	22,600 ±550	UCLA-536	too old to calibrate
Haynes (1967)[2]	21,600 ±550	UCLA-536A	too old to calibrate
Bell (1991) unpub.	18,690 ±170	GS-2958	21,803 – 22,613 cal BP (~22)
Quade (1986)[2]	15,000 ±500	-	16,662 – 19,138 cal BP[2] (~18)
Quade (1986)[2]	14,000 ±500	-	15,344 – 18,475 cal BP[2]

1 – calibration ref.
2 – modified from original: Haynes date minus 1000 years to account for the local chemistry of gastropods used in dating (Haynes, 1967; Quade, 1986). Quade (1986) made estimates of the age of the top of Unit D, but discussed ages in terms of radiocarbon years, not calibrated, so I calibrated his estimated ages to get a better idea of the absolute time involved, and assigned a ± 500 year uncertainty (half the time between Quade's constraints – 1000 years) to his values; these modifications are done to get an idea what Quade's constraints would be and not to be used rigorously.

The best estimate for the time over which the Eglington warp was formed is 22 ky; this is the approximate average of Bell's (1991, unpub.) range of calibrated dates, and the presumption is that the warping started shortly before this date, assigned as approximately the date itself. The range of possible time estimates (approximately two sigma error range) is 16.5 to 25 ky. The minimum estimate is the minimum calibrated age of Quade's (1986) age estimate of the top of Unit D, and the maximum age is taking Hayne's (1967) date of the middle of Unit D and approximately calibrating it by adding 3000 years to it.

Offset estimates of Unit D

The vertical displacement of Unit D based on topographic offsets of the surface, maximum of about 25 m (Haynes, 1967), and in another location offset of a carbonate unit near the top of Unit D has been measured at about 14 m (Nitchman and others, 1991). Profiling the surface scarp from DEM's confirms a 14 to 25 m height to the Eglington warp (Taylor and dePolo, in prep.), with the highest scarp measurements only over a small reach in the central part of the fault. Unit D is generally buried on the hanging wall. The general displacement profile of the Eglington fault is typical of faults with a higher central portion tapering towards the ends of the fault, and supports a single-segment hypothesis for the fault (i.e., displacement is not the highest at the south end as it might be if it were part of a larger earthquake segment).

In the Ann Road area, a paludal carbonate layer near the top of Unit D could be seen in gullies to continuously warp down the scarp, and into the hanging wall with a fairly even thickness (~30 to 50 cm). It seems unlikely that this spring-related deposit would form with an even thickness if there was any significant escarpment present at the time of the carbonate formation, thus the monoclinal deformation followed the carbonate deposition, that is the deposition of the upper part of Unit D.

Estimates of the offset of Unit D range from 14 to 25 m; Nitchman and others (1991) measured the 14 m minimum height, and Haynes (1967) and Taylor and dePolo (unpub.) measured a monoclinal warp height of ~25 m in at least one place along the fault, although there could be some erosion on the hanging wall potentially causing this value to be a little too large. The preferred offset estimate is 21 m; this is a solid maximum height measured by Taylor and dePolo (unpub.). Taylor and dePolo (unpub.) measured higher scarp measurements (18 m and 21 m) on either side of where Nitchman and others (1991) made their measurement, so a higher value than what they measured seems likely.

[need to measure topo. height right at Nitchman+ measurement site]

Unit D slip rate estimates

Fault slip rate estimates for the Eglington fault are derived from the above preferred, maximum, and minimum values (Table 2).

Table 2 Input values and late Quaternary slip rates for the Eglington fault

Parameter	Preferred Value	Minimum Value	Maximum Value
Amount of offset	21 m	14 m	25 m
Time of offset	22 ky	16.5 ky	25 ky
Fault slip rate	0.95 m/ky	0.16 m/ky	1.5 m/ky

Older slip rate estimates

Two older offset measurements along the Eglington fault have been made, 220 m of offset of the basement (Plume, 1984) and a 50 m offset of older basin sediments (Maxey and Jameson, 1948). The later offset, based on "drillers logs" is hard to assign an age to for a rate, but is noted to only be two to three times larger than the offset across the surface warp. A rough estimate can be made using the basement offset by considering the age of the basin opening as a constraint. This is a Miocene value, in tens of millions of years, that would be on the order of a ten thousandth; because this age spans multiple seismotectonic regimes, any derived slip rates from this older basement offset is not relevant for the modern tectonic regime.

The Eglington fault appears to be in an episode of activity that spans from latest Pleistocene to the present, which is consistent with the warped nature of the surface expression of the fault (sediments were deposited over the fault before it began to move during this recent episode). Subsurface offset measurements being only about half of the surface are consistent with a lower rate of activity prior to latest Pleistocene. At least one Holocene event is also consistent with a relatively high rate of activity along the Eglington fault.

Earthquake Segmentation

There is no logic that indicates that the Eglington fault should be segmented, it appears to be a single earthquake segment. The question is more, should the Eglington fault be segmented from the Decatur fault zone to the south? Subsurface reconstructions along the northernmost Decatur fault indicate the fault is well developed at depth, and likely coincides with a basement offset (Donovan, 1996; see section BB' on his page 104). The Eglington fault appears to be a single, continuous structure, although there are likely some complexities in the folding and faulting along stike. The northeast end of the Eglington fault is likely truncated by a cross fault at the Las Vegas Wash (Nitchman and others, 1991). This truncation may be important for understanding how the Eglington fault could have some much offset, yet be such as short structure (short-fat-fault problem). A cross-structure would allow a relatively large displacement on the main fault to approach its end and be accommodated by the cross-structure. Displacement at the southern end of the Eglington fault appears to distribute across multiple fault traces and die out.

Single-Event Displacements

Only a minimum estimate of a single-event displacement is available from an offset along a single fault trace during the most-recent event (PE1); this vertical offset is estimated from the thickness of a small colluvial wedge formed against a small fault scarp and is __ cm (Taylor and dePolo, in prep.)

Comments

There has been debate over the origin of the Eglington scarp (and other faults within Las Vegas Valley). An early hydro-compaction hypothesis was forwarded for all faults within Las Vegas Valley by Maxey and Jameson (1948). This aseismic driving mechanism was adopted for decades, and little consideration was given to any seismogenic potential from faults within the valley. But several factors were inconsistent with this hypothesis, and a tectonic, seismogenic origin has been shown to be consistent with existing data (Bell, 1981; Bell and dePolo, 1998; Slemmons and others, 2001; dePolo and others, 2006). The largest inconsistency of the compaction hypothesis is that the amount of sediment thicknesses available to create differential compaction is not enough for the sizes of late Quaternary fault scarps and warps that exist (Bell, 1981). Another inconsistency is that bedrock offsets below the basin fill have been found below several of the faults, which should sole within the basin if they are only related to sediment compaction. In the case of the Eglington fault, 220 m of basement offset below the warp has been measured (Plume, 1984). Also in the case of the Eglington fault, there is not a change of sedimentary facies across the fault to create the setting for differential compaction; facies changes do occur for several faults, however, these may be created by tectonic fault activity ponding sediments near scarps, as can be observed in the recent sedimentation patterns (c.f., Matti and Bachhuber, 1985).

In contrast, basement offsets are expected for tectonic faults, and they exist.

Ithaca Avenue Fault

Two strands of the IAF cut a late Pliocene(?) to early Quaternary fanglomerate along the northwestern flank of the River Mountains east of Ithaca Avenue (T 21 S, R 63 E, section 3). Both strands strike 335-340° and dip 70° W.

The IAF is recognized by the presence of disturbed bedding in the Red Sandstone Unit in a small wash where the two strands bifurcate and by the presence of offset pediment surfaces on the late Pliocene(?)-Quaternary fanglomerate. To the south, the joined strands are covered by modern alluvial and colluvial sediments at the base of the mountain front. Minor, poorly exposed scarps in young sediments are present along the western mountain front south of the Interior Valley drainage at the River Mountains Water Treatment Facility. Drainages along the presumed trace of the IAF display multiple stream terraces and beheaded drainages. In addition, the mountain front is linear and strongly beveled in profile with prominent 10-20 meter-high ledges at the base locally (D.B. Slemmons, 2006 personal communication). To the north, the strands appear to die out and/or are obscured on the surface by human activity resulting from the construction of high-tension power lines and a bike path.

East of Ithaca Avenue, the western strand is the more prominent one and can be traced for nearly 900 m from the mountain front. A topographic profile measured along a ridge in a Quaternary fanglomerate indicates an 8.4 m vertical offset of the fan surface. The throw was measured by: (1) determining the far-field slopes of the current fan surface, which are presumed to be that of the pre-faulted surface; (2) drawing a best fit line through the far-field slopes; and (3) measuring the vertical offset (Δy) at any point (x) on the graph (Chapter 3; Pinter, 1996).

The eastern strand is 650 m long, is less sinuous, and has a smaller vertical offset value of 1-2 m. Because the scarp-face and footwall are badly eroded, a profile was not measured.

Ithaca Avenue Fault – River Mountains

The IAF is a previously recognized, but unnamed northwest-striking, west-facing fault along the northwest River Mountains (Bell and Smith, 1980; Slemmons et al., 2001) near Ithaca Avenue and Racetrack Road. Here, the IAF cuts a late-Pleistocene (50,000? year old) fanglomerate containing stage II carbonate soil development (D.B. Slemmons, personal communication 2006). Topographic profiling of the IAF documents: (1) the fan slope, scarp slope, and scarp height; and (2) the presence of a beveled scarp slope, indicating multiple rupturing events (Hanks et al., 1984).

Further evidence suggesting multiple rupturing events on the IAF is the 8.4 m scarp height, which is too large a slip for the magnitude of earthquake that can be induced from rupturing the entire length of the Frenchman Mountain-IAF system based on the regression plots of Wells and Coppersmith (1994). Using a surface rupture length of 10 km for the IAF south of the Las Vegas Wash (proceeding paragraph), and a surface rupture length of 38 km involving the entire trace of the Frenchman Mountain-IAF system (Slemmons, 2001), the maximum predicted vertical displacements are ~0.5 and 1.8 m, respectively (Wells and Coppersmith, 1994). Unfortunately, the presence of multiple rupturing events negates the usefulness of diffusion models to estimate a most recent (rupturing) event (MRE) age (Pinter, 1996).

Although the exposed trace of the IAF is less than 1 km for the two strands, the presence of such a large scarp height, and possible fault scarp-like morphologies along the southwestern River Mountains range front (C. dePolo, personal communication 2006; D.B. Slemmons, personal communication 2006), indicates a much longer rupture length. The limited exposure of the IAF is likely a combination of (1) discontinuous surface rupture during previous earthquakes, (2) subsequent erosion and deposition, and (3) human disturbance and urbanization. Therefore, if the IAF cuts the immediate substratum of the Las Vegas Wash, west of the Calico Hills neighborhood, to just south to the River Mountains Water Treatment Facility at the mouth of the Interior Valley drainage, the rupture distance is 8.5 – 10 km. A regression plot of surface rupture length versus moment magnitude suggests then that the IAF is capable of producing a 6.2 M_w earthquake. This is slightly less than the 6.4 M_w predicted by Slemmons and others (2001) due to them projecting the IAF further south to near Railroad Pass.

Using only the 1 km of exposed surface rupture length on the IAF, a maximum magnitude of 4.9 – 5.1 is estimated. However, < 5.0 magnitude earthquakes are not likely to produce surface rupture, and thus the aforementioned surface rupture lengths are better approximations (Slemmons et al., 2001).

References

Bell, J.W., 1981, Subsidence in Las Vegas Valley: Nevada Bureau of Mines and Geology Bulletin 95, 84 pp..

Bell, J.W., Ramelli, A.R., and Caskey, S.J., 1998, Geologic map of the Tule Springs Park Quadrangle, Nevada: Nevada Bureau of Mines and Geology, Map 113, scale 1:24,000.

Bell, J.W., Ramelli, A.R., dePolo, C.M., Maldonado, F., and Schmidt, D.L., 1999, Geologic map of the Corn Creek Springs Quadrangle, Nevada: Nevada Bureau of Mines and Geology, Map 121, scale 1:24,000.

Donovan, D.J., 1996, Hydrostratigraphy and allostratigraphy of the Cenozoic alluvium in the northwestern part of the Las Vegas Valley, Clark County, Nevada: University of Nevada, Las Vegas, M.S. Thesis, 199 p.

Haynes, C.V., 1967, Quaternary geology of the Tule Springs area, Clark County, Nevada, *in* Wormington, H.M. and Ellis, D., edts., Pleistocene studies in southern Nevada: Nevada State Museum of Anthropology, Paper No. 12, p. 1-104.

Matti, J.C. and Bachhuber, F.W., 1985, Geologic map of the Las Vegas SW Quadrangle: Nevada Bureau of Mines and Geology, Map 3Bg, 1:24,000 scale.

Maxey, G.B., and Jameson, C.H., 1948, Geology and water resources of Las Vegas, Pahrump, and Indian Spring Valleys, Clark and Nye counties, Nevada: Nev. State Engineer's Office, Water Res. Bull. 5, 121 pp.

Bell, J.W., and dePolo, C.M., 1998, On the origin of Quaternary fault scarps in Las Vegas Valley: NBMG Open-File Report, Report: 98-6, 70 pp.

dePolo, C.M., Bell, J.W., Boron, S., Slemmons, D.B., and Werle, J., 2006, Latest Quaternary Fault Movement along the Las Vegas Valley Fault System, Clark County, *Nevada*: Environmental & Engineering Geoscience. V. 12, p. 181-193.

Quade, J., 1986, Late Quaternary environmental changes in the upper Las Vegas Valley, Nevada: Quaternary Research, v. 26, p. 340-357.

Nitchman, S.P., Ramelli, A.R., and Taylor, J., 1991, Eglington scarp: Nevada Bureau of Mines and Geology, Preliminary fault evaluation report, 6 p., unpublished.

Zuckerman, J.M., 1998, The controversy over the origin of the Eglington fault, in dePolo, C.M., edt., Seismic Hazards in the Las Vegas region: Nevada Bureau of Mines and Geology, Open-File Report 98-6, p. 197-204.

Slemmons, D.B., Bell, J.W., dePolo, C.M., Ramelli, A.R., Rasmussen, G.S., Langenheim, V.E.,

Smith, K., and O'Donnell, J.O., 2001, Earthquake hazard in Las Vegas, Nevada: Proceedings, 36th Annual Symposium on Engineering Geology and Geotechnical Engineering, p. 447-459.

Taylor, W. and dePolo, C.M., in preparation, Preliminary characterization of the Eglington fault, Las Vegas basin, Nevada: University of Nevada, Las Vegas, Final Technical Report to the U.S. Geological Survey National Earthquake Hazard Reduction Program.