2018 Working Group on Nevada Seismic Hazards
February 5-6, 2018 Reno, Nevada

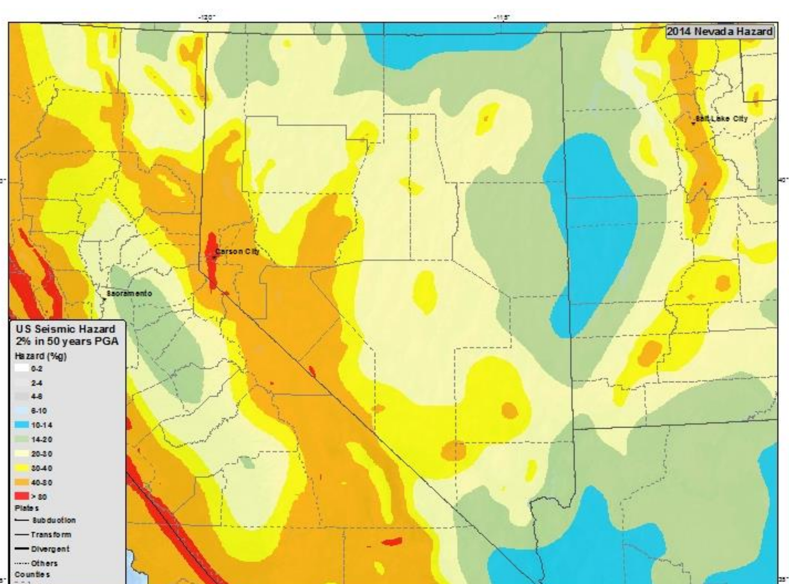
Nevada Bureau of Mines and Geology
1664 N. Virginia St., MS 178
Scrugham Engineering/Mines building
University of Nevada, Reno
Reno, NV 89557

Nevada Seismological Laboratory
1664 N. Virginia St.
Laxalt Mineral Engineering Building, Rm. 322
University of Nevada, Reno
Reno, NV 89557

Welcome to the 2018 Working Group on Nevada Seismic Hazards located in the Harry Reid Engineering Building conference room on the University of Nevada, Reno campus.

The main goal of the meeting is to review ongoing earthquake hazard research in Nevada, discuss technical issues related to earthquake hazards in Nevada, and identify priorities for future research that will reduce uncertainties and improve the USGS Earthquake Hazard Model.
The workshop will include technical presentations and discussions focused on: 1) Quaternary fault parameters and earthquake probabilities, 2) seismicity and geodesy, and 3) ground motions relevant to the Reno-Carson-Lake Tahoe and Las Vegas regions.

The meeting is open to all persons with relevant interest and experience. Attendees are encouraged to present their recent relevant research, with the goal of improving the US Geological Survey hazard model as it affects hazard estimates in Nevada. Attendees are also asked to identify, based on their professional judgment, the most important research issues needed to improve the USGS hazard model for the region.



2014 USGS Seismic Hazard Map for Nevada

AGENDA

2018 Working Group on Nevada Seismic Hazards Workshop

February 5 and 6, 2018, Reno, Nevada

Day 1. February 5. Quaternary fault parameters and seismic hazards

8:30 – 8:45 Introductory remarks – Koehler and Anderson

8:45 – 9:00 Update on the USGS External Grants program – Gold

9:00 – 9:20 Anderson, J.G., 2018, **Building the Nevada Hazard Map: Information needed and some important uncertainties**

9:20 – 9:40 Petersen, M., Zeng, Y., Gold, R., and Shumway, A., 2018, **The 2018 and 2020 U.S. National Seismic Hazard Model for Nevada**

9:40 – 10:00 Wong, I., Lund, W., DuRoss, C., Thomas, P., Arabasz, W., Crone, A., Hylland, M., Luco, N., Olig, S., Pechmann, J., Personius, S., Petersen, M., Schwartz, D., and Smith, R., 2018, **Insights into Basin and Range seismic hazards from the Working Group on Utah Earthquake Probabilities**

10:00 – 10:20 Coffee Break

Northern Nevada

10:20 – 10:40 Wesnousky, S., 2018, **Questions bearing on the estimation of seismic hazard in the Reno-Carson-Lake Tahoe region**

10:40 – 11:00 Koehler, R.D., 2018, **Efforts to better characterize the seismic potential of faults in the North Valleys region, Reno, Nevada**

11:00 – 11:20 Pierce, I.K.D., Wesnousky, S.G., and Owen, L.A., 2018, **The Search for strike-slip in the Northern Walker Lane: New slip rates and characterization of active faults in Antelope, Mason, and Smith valleys, Nevada**

11:20 – 11:40 Angster, S., 2018, **New estimates on the rate of slip for faults of the Central Walker Lane**

11:40 – 12:00 dePolo, C., Gold, R., Briggs, R., Crone, A., Mahan, S., and Borchardt, G., 2018, **Recent Paleoseismicity of the Kings Canyon Fault Zone between Ash and Vicee Canyons, Carson City, Nevada**

12:00 – 1:20 Lunch

Southern Nevada

1:20 – 1:40 Taylor, W.J., Abdelhaleem, S., Peck, A., Dee, S., and dePolo, C, 2018, **Fault interactions along a N-S belt around 114.75 degrees W longitude in southern Nevada**

1:40 – 2:00 Dee, S., dePolo, C., Taylor, W., Mahan, S., 2018, **New paleoseismic data from the Frenchman Mountain fault, Las Vegas**

2:00 – 2:20 dePolo, C., Taylor, W., and Dee, S., 2018, **The Las Vegas Valley Fault System – A 2017 progress report**

2:20 – 2:40 Gold., R., Briggs, R., dePolo, C., Dee, S., and Petersen, M., 2018, **Seeking input on the inclusion of the Eglington fault, Nevada, in the National Seismic Hazard Map**

2:40 – 3:00 Break

3:00 – 3:20 Summary of Quaternary fault parameters and future directions – Koehler

3:20 – 4:20 Discussion: Implications to the National Seismic Hazards Map and priorities for future research- All

4:20 – 4:30 Summary and concluding remarks – Koehler and Anderson

4:30 Adjourn

<u>Day 2. February 6. Seismicity, ground motions, and geodesy</u>

8:30 – 8:45 Introductory remarks – Koehler and Anderson

8:45 – 9:05 Smith, K.D., Hatch, R.L., Ruhl, C.J., Kent, G.M., Kell, A., Slater, D., Plank, G., Williams, M., Cassar, M., Rennie, T., Torrisi, J., and Presser, R., 2018, **Review of Nevada and Eastern California Seismicity and the Nevada Seismic Network**

9:05 – 9:25 Ruhl, C.J., Smith, K.D., Abercrombie, R.E., Kent, G.M., Zaliapin, I., and Hatch, R.L., 2018, **Characterizing Earthquake Sources in the Urban Reno-Carson-Lake Tahoe Regions**

9:25 – 9:45 Hatch, R., Ruhl, C., Smith, K, and Abercrombie, R., 2018, **Precise relocations, source parameters, and directivity effect for five recent earthquake sequences near Nevada Urban Areas**

9:45 – 10:05 Anderson, J.G., Biasi, G.P., and Wesnousky, S.G., 2018, **Fault-Scaling Relationships Depend on the Average Fault-Slip Rate**

10:05 – 10:30 Coffee Break

10:30 – 10:50 Dickenson, S., and Louie, J.N., 2018, **Characterization of Earthquake Ground Motions for Engineering Design in the Reno Basin: Geotechnical and Seismological Perspectives**

10:50 – 11:10 Louie, J.N., Dunn, M., and Pancha, A., 2018, **Comprehensive Community Velocity Models for Nevada's Urban Basins: The Key to Predicting Earthquake Ground Motions**

11:10 – 11:30 Ahdi, S.K. , Stewart, J.P. , Kwak, D.Y., Yong, A., Sadiq, S., Ilhan, O., Park, D., Hashash, Y.M.A., and Bozorgnia, Y., 2018, **Development of a Community Shear-Wave Velocity Profile Database in the United States**

11:30 – 11:50 Dunn, M., Louie, J., Smith, K.D., Dickenson, S., and Hatch, R.L., 2018, **Investigating basin amplification factors for shaking in the Reno-Tahoe and Las Vegas regions for local and regional events**

11:50 – 1:30 Lunch

1:30 – 1:50 Bormann, J., Hammond, W.C., Kreemer, C., and Blewitt, G., 2018, **GPS constraints on present-day slip rates in the northernmost Walker Lane: Reno, Carson City, and Tahoe region, NV and CA**

1:50 – 2:10 Hammond, W., Kreemer C., and Blewitt, G., 2018, **Robust Estimation of Fault Slip Rates Using GPS Imaging in the Walker Lane and Western Great Basin**

2:10 – 2:30 Kreemer, C., Young, Z. Hammond, W., Blewitt, G., 2018, **Robust Estimation of the Secular and Time-Variable Strain Rate Field in the American Southwest**

2:30 – 2:50 Brune, J, 2018, **Update on PBR Constraints on Ground Motion from Normal Faults**

2:50 – 3:10 Break

3:10 – 4:10 Discussion: Implications to the National Seismic Hazards Map and priorities for future research - All

4:10 – 4:30 Summary of seismicity, ground motions, and geodesy and concluding remarks – Koehler and Anderson

4:30 Adjourn

Abstracts
Day 1, February 5, 2018

Building the Nevada Hazard Map: Information needed and some important uncertainties

John G. Anderson

Nevada Seismological Laboratory, University of Nevada, Reno, NV 89511

Seismic hazard maps are built from seismic hazard curves. The hazard curve that uses an amplitude of ground motion on the x-axis, and the y-axis gives the average annual rate of exceedance of that ground motion. Many different amplitudes of ground motion are used, and unique hazard curves exists for each at every point on the Earth. Hazard curves should be thought of as the outcome of a conceptual experiment, based on statistics of ground motions observed at that point over a long time. Unfortunately, because the user community is interested in annual exceedance rates smaller than 10^{-3} per year, the measurement cannot be performed, but I take the description of an experiment to measure it as evidence for existence.

Considering this, hazard curves need to be calculated. Two types of input are needed. The first is a seismicity model, i.e. a description of the location, magnitude, and occurrence rates of all earthquakes in the region. The second is a ground motion prediction equation (GMPE), i.e. a model that gives an estimate of the amplitude of the ground motion of interest for each possible earthquake in the seismicity model.

The seismicity model is generally a composite model that considers all known faults, and "area sources" that allow for the possibility of unknown large faults and characterize the distribution of small earthquakes. The rates of earthquakes on the known faults are established by a moment balance. In other words, the slip rate based on geological or geophysical information is set to balance the rate of earthquakes. A critical input to this moment balance is the description of the subsurface fault geometry and estimates of the sizes of earthquakes that can occur on the fault. Seismic network data is used to characterize the distribution of locations of small earthquakes. A method is used to "smooth" the distribution of locations of events in the catalog. Catalog magnitudes need to be converted to moment magnitude using a regional conversion scheme that considers uncertainties. California has systematically compared the final USGS model to the historical rates of earthquakes as an overall check.

The 2014 National Seismic Hazard Map considers alternative published GMPEs. Acceptable models need to meet a long list of standards established by the USGS. While this is the most practical approach, state-of-the-art hazard estimates attempt to adjust the GMPE to specific regions, or at least select the GMPEs on the basis of which ones best fit available data from the region. The next generation of hazard maps will use estimated depths of sedimentary basins in estimates of some of the considered ground motion parameters. An essential part of every GMPE is a description of the uncertainty in the estimate of the ground motion parameter, and this uncertainty can have a strong effect on the final results.

The probabilistic seismic hazards in the larger cities of western Nevada are dominated by the Mount Rose and Carson Range faults. These are normal faults; Reno and Carson City are on the hanging wall. I have examined the sensitivity of the hazard posed by these faults to uncertainty of dip, slip rate, magnitude, and choice of GMPE for an earthquake that ruptures the length of each fault. SA(0.01s) with exceedance probability of 2% in 50 years was determined for each branch of a logic tree for those properties. The distribution of SA(0.01s) values, weighted by the branch weights, is fit with a lognormal probability distributions. The standard deviation is used as an alternative to the 15- and 85-percentile values to track the width of this distribution. This measure of the epistemic uncertainty of the hazard estimate generally increases with distance, but is also high on the hanging wall. Tornado plots show that on the hanging wall, the uncertainties in fault dip and the choice of the GMPE dominate. On the foot wall and at intermediate distances in all directions, uncertainties in fault slip rate dominate, while at larger distances uncertainties in the magnitude of the full-fault rupture dominate. This study does not examine all the contributions to the hazard. Smaller earthquakes on the subject faults, other faults, and background sources all contribute to the total hazard, and dominant at larger distances. Thus, the results are limited, and furthermore cannot be generalized to other exceedance rates or response spectral periods. It is nevertheless notable that each of the considered parameters is the dominant source of epistemic uncertainty in at least one of the sampled locations.

The 2018 and 2020 U.S. National Seismic Hazard Model for Nevada

Petersen, M., Zeng, Y., Gold, R., and Shumway, A.

U.S. Geological Survey, Golden, CO

The USGS plans to update the National Seismic Hazard Model (NSHM) in 2018 and 2020 to account for recent scientific developments. These models have been the basis for building codes, insurance rate structures, and public policy decisions and it is critical that only the best available science is incorporated in these models. The plan for updating the maps in 2018 includes: (1) incorporating new ground motion models for the central and eastern U.S., (2) applying ground motion models that incorporate basin depth in the Western U.S., and (3) updating the earthquake catalog and smoothed seismicity models. The update plan for the 2020 model needs to be published by June, 2018. Currently we are considering the following updates: (1) update of the geodetic and geologic joint inversion data for estimating crustal fault recurrence, (2) implement logic trees for faults in the Las Vegas basin, (3) incorporate magnitude-area equations with slip-rate parameters, and (4) refine models that incorporate basin information in the ground motion models. Some of these updates may be incorporated in future models if they are not sufficiently documented and accepted in the NSHM workshops. The USGS is open to suggestions on how the models can be improved in the future.

Insights into Basin and Range seismic hazards from the Working Group on Utah Earthquake Probabilities

By the Working Group on Utah Earthquake Probabilities

Ivan Wong, William Lund, Christopher DuRoss, Patricia Thomas, Walter Arabasz, Anthony Crone, Michael Hylland, Nicolas Luco, Susan Olig, James Pechmann, Steve Personius, Mark Petersen, David Schwartz, and Robert Smith

After a nearly six-year effort, the Working Group on Utah Earthquake Probabilities (WGUEP, 2016) published its earthquake forecast for the Wasatch Front region in Utah, Idaho, and Wyoming (Figure 1). The WGUEP estimated a 43% chance of one or more large (**M** ≥ 6.75) earthquakes occurring in the Wasatch Front region in the 50-year period from 2014 to 2063 and a 57% probability of one or more **M** 6.0 and larger earthquakes. The probability of one or more surface-faulting earthquakes along the Wasatch fault was estimated to be 18% in the next 50 years.

Although not a hazard study, the forecast focused on characterizing Quaternary active faults (Figure 2) and background seismicity following the same process that is needed for seismic source inputs for a probabilistic seismic hazard analysis. Particular attention was paid to adequately characterizing the epistemic uncertainties in the models and parameters. Several issues regarding the characterization of Quaternary faulting and background seismicity in the Wasatch Front region were addressed in the WGUEP analysis. These issues have direct bearing on the evaluation of seismic hazard elsewhere in the Basin and Range Province, including Nevada. The following are some key elements of the methodology employed by the WGUEP.

1) The rupture models for faults emphasize segmentation models which allow for both single-segment and multi-segment rupture. For the best-studied faults such as the Wasatch and Oquirrh-Great Salt Lake fault zones, we relied heavily on the paleoseismic evidence from fault trenching (Figure 3). For 45 other faults and fault segments (Figure 2), segmentation was based on limited paleoseismic and structural arguments.
2) Characteristic magnitudes (M_{char}) were calculated from rupture dimensions and displacements. A significant effort was made to review the existing empirical relations between magnitude and various fault parameters and select relations which best fit the event displacement data for the Wasatch fault. The magnitude relations based on average displacement or seismic moment yield magnitudes that exceed those based on surface rupture length and rupture area for the Wasatch fault. This difference had to be reconciled.
3) The probability calculations used both time-independent and time-dependent average recurrence intervals for large surface-faulting earthquakes on the central Wasatch fault segments (Figure 3) and the Great Salt Lake fault segments, based on their paleoseismic chronologies. The time-dependent recurrence intervals were estimated using the Brownian Passage Time (BPT) model. An important issue was characterizing the periodicity of the large earthquakes through the choice of the coefficient of variation (COV).
4) The magnitude-frequency relationships assumed for faults and fault segments were the maximum magnitude model and two different doubly-truncated exponential models (6.75 ≤ **M** ≤ M_{char}), with weights that depended on the rupture model and the characteristic magnitude. The weighting of these models was subjective given that the historical record, particularly in the

Basin and Range Province including the Wasatch Front region, indicates that the observed seismicity is generally off-fault.

5) For antithetic fault pairs such as the Salt Lake City segment/West Valley fault pair, we put considerable effort into characterizing the maximum magnitudes, rupture behavior (simultaneous or independent) and activity rates.
6) To quantify the rates of background earthquakes, the WGUEP developed a robust and comprehensive earthquake catalog for the Wasatch Front region for the time period 1850 through September 2012. This task entailed estimating magnitudes of pre-instrumental events, converting all magnitudes uniformly to moment magnitude, and removing induced earthquakes. Our background seismicity rate calculations with this catalog accounted for magnitude uncertainties.
7) Moment rates estimated from the geodetic data were compared to geological and seismological moment rates across the Wasatch Front region and four subregions. The WGUEP did not use geodetic data directly for estimating fault slip rates, as has been done by the USGS in the National Seismic Hazard Maps, due in large part to the robust paleoseismic record available for the Wasatch fault and our reliance on recurrence intervals.

The maximum magnitude ($\mathbf{M}_{max}$) for background earthquakes is a controversial and significant issue. The USGS assigns most of the $\mathbf{M}_{max}$ weight to $\mathbf{M}_{max}$ 7.45 in the National Seismic Hazard Maps for the western U.S. (including Utah) because they believe that the inventory of Quaternary faults in the western U.S. is incomplete. The WGUEP believes the inventory of Quaternary faults that are capable of generating surface-faulting earthquakes is complete or nearly complete in the Wasatch Front region. Hence, using the minimum magnitude for surface faulting as a basis for the Mmax, the WGUEP adopted an $\mathbf{M}_{max}$ of 6.75 ± 0.25 for background seismicity.

We compared the earthquake magnitude-frequency distribution (MFD) determined from the earthquake catalog with the MFD for all seismic sources in the WGUEP source model. A mismatch (bulge) is observed at $\mathbf{M} \geq 5.5$. However, our paleoseismic estimate of the recurrence rate of large surface-faulting earthquakes in the Wasatch Front region is in excellent agreement with the MFD.

REFERENCES

Working Group on Utah Earthquake Probabilities, 2016, Earthquake probabilities for the Wasatch Front region in Utah, Idaho, and Wyoming: Utah Geological Survey Miscellaneous Publication 16-3, 164 p. plus 5 appendices.

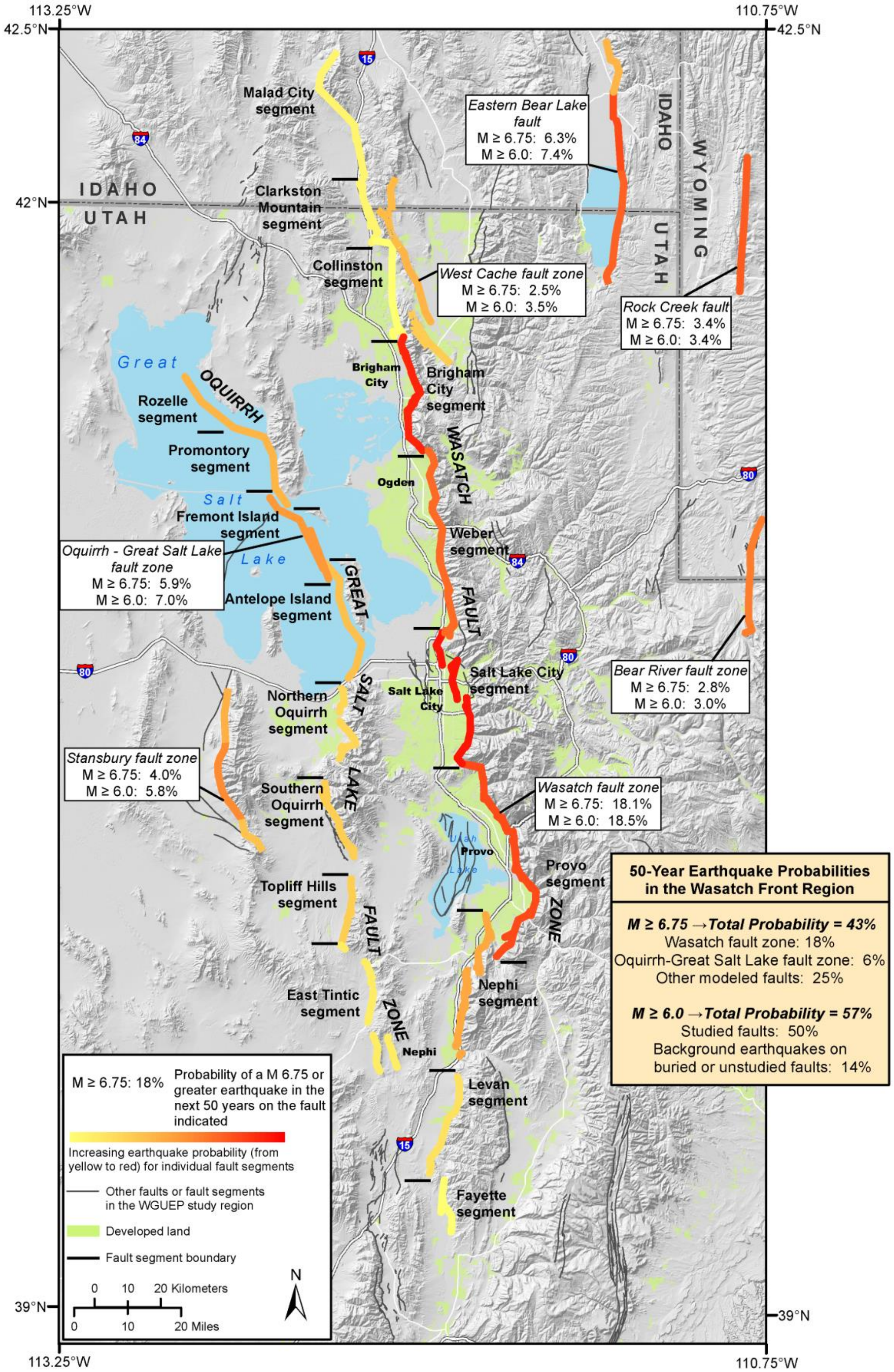


Figure 1. Probabilities of one or more earthquakes of **M** 6.0 and 6.75 or greater in the next 50 years (2014-2063) in the Wasatch Front region (WGUEP, 2016).

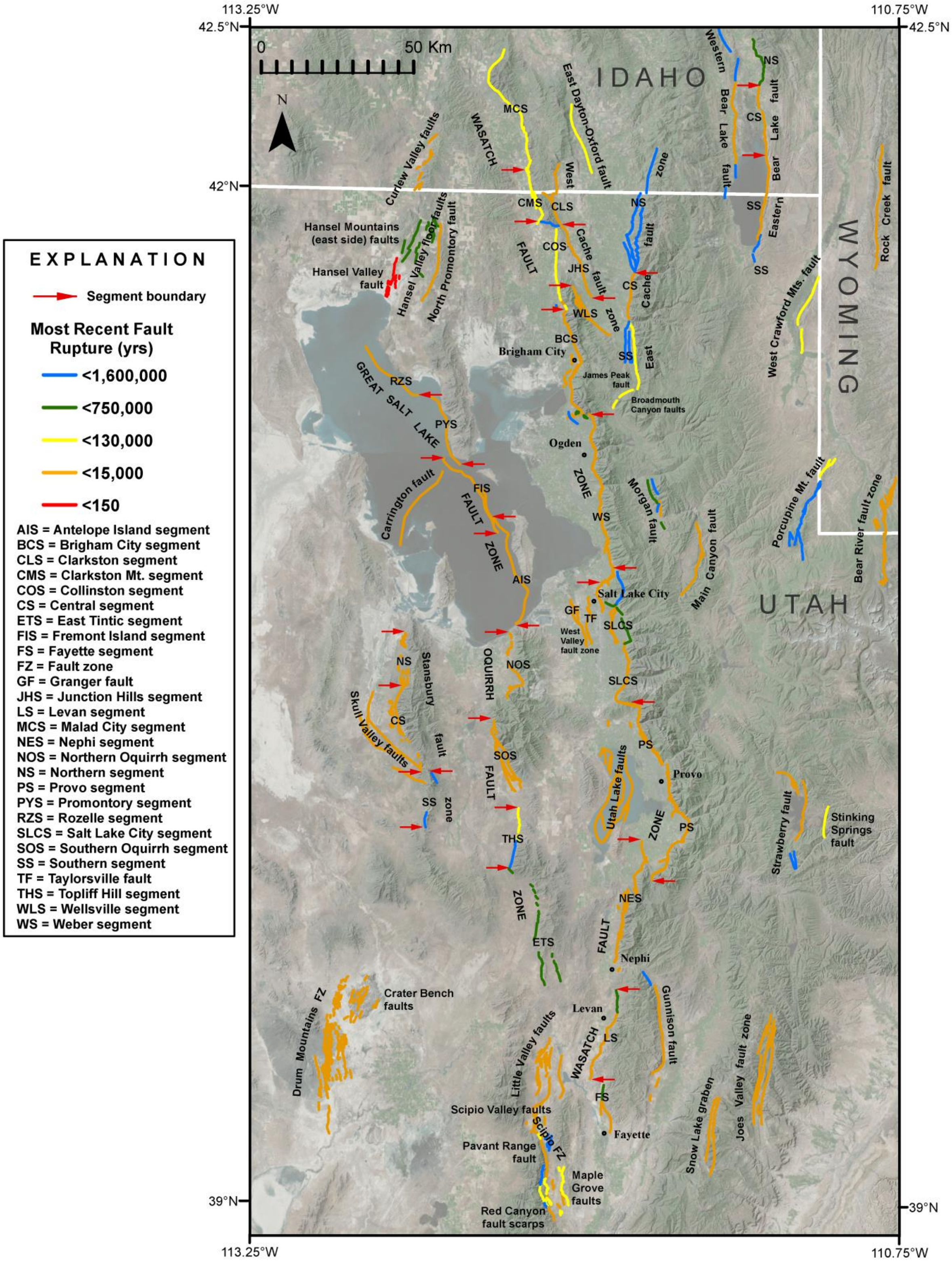


Figure 2. Faults and fault segments included in WGUEP forecast (WGUEP, 2016).

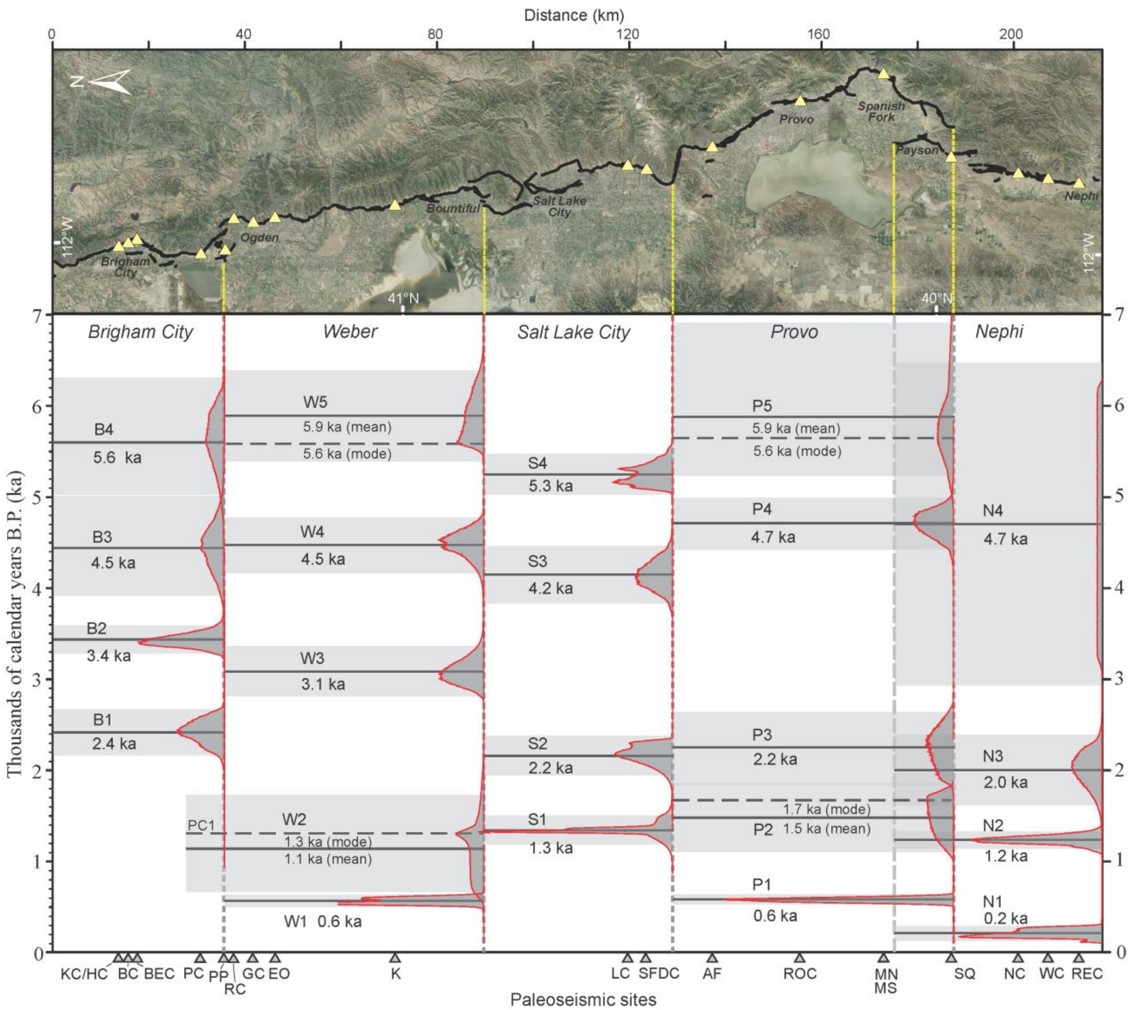


Figure 3. Single-segment rupture model for the central WFZ (WGUEP, 2016). The lower panel shows times of earthquakes on each segment. Solid horizontal lines indicate mean earthquake times and dashed horizontal lines indicate modal times for some earthquakes. The gray boxes show 2σ time ranges. Red lines with gray-shaded fill are earthquake probability density functions derived from the WGUEP integration of site paleoseismic data.

Questions bearing on the estimation of seismic hazard in the Reno-Carson-Lake Tahoe region

Steven G. Wesnousky

Center for Neotectonic Studies and Nevada Seismological Laboratory

University of Nevada, Reno 89557

A region of transtension in the northern Walker Lane, the Reno-Carson-Lake Tahoe region encompasses normal faults, and both right-lateral left-lateral faults. The sources of potentially large earthquakes in the Reno-Carson-Lake Tahoe appear well defined. Significant sources proximal to the region include the major normal faults of Carson and Washoe Valleys and Lake Tahoe Basin, the Little Valley fault zone and its extension toward Reno, the East Carson Valley fault zone, the right-lateral Warms Springs, Pyramid Lake and Polaris faults to the east and west of Reno, and the left-lateral faults of the Olinghouse and Carson lineaments. Less though can be said of the confidence in estimates bearing on the recurrence rates, the rupture lengths and size of future large earthquakes on these sources. The uncertainties arise due to factors ranging from lack of paleoseismic information, questions of how faults may link to one another during large earthquakes, and an inability at this stage to match well the deformation rates being reported by geodesy as compared to those assessed from geology.

Efforts to better characterize the seismic potential of faults in the North Valleys region, Reno, Nevada

Rich D. Koehler

Nevada Bureau of Mines and Geology, University of Nevada, Reno

The North Valleys are an approximately 60 km X 60 km region of active north and northeast trending faults that pose a direct seismic hazard to the rapidly expanding Reno urban area. Normal oblique (dextral) faults of the Sierra Nevada frontal fault system and dextral strike-slip faults of the northern Walker Lane bound the North Valleys on the west and east, respectively, and accommodate the majority of the Pacific/North American plate boundary strain at this latitude. Although the faults of the North Valleys are only moderately expressed in the geomorphology, discontinuous scarps in mid-Pleistocene deposits, triangular facets, and observations from reconnaissance trenching indicate that many of the faults are active. This activity is reflected in contemporary geodetic studies which indicate that the faults of the North Valleys may collectively accommodate 0.9-1.2 mm/yr of extension and <0.3 mm/yr of dextral slip (Bormann, 2013). Despite the general lack of geologic studies and limited paleoseismic data, the 2014 update of the National Seismic Hazards Map (NSHM) included faults of the North Valleys using modeled slip rates. Faults used in the model include the Petersen Mountain, Fred's Mountain, Spanish Springs Valley, Spanish Springs Peak faults. Notably absent are the Western Lemmon Valley and Hungary Valley faults, as well as the Last Chance fault zone in California.

In this presentation, I describe recent efforts of the NBMG to better characterize hazardous faults in the Reno area (including the North Valleys). Additionally, I present Quaternary fault parameters compiled for faults within an approximately 100 km radius of downtown Reno (focus area) in an effort to begin discussions on how to best prioritize faults for additional research that will have the greatest impact on future updates of the NSHM. Although not the focus of this talk, the NBMG is involved in similar efforts to better characterize Quaternary faults and prioritize future research in the Las Vegas valley.

During 2018, NBMG will be conducting two paleoseismic studies within and adjacent to the North Valleys including investigations along the Petersen Mountain and Warm Springs Valley fault zones. Both projects will focus on detailed Quaternary geologic strip mapping, identification of active fault strands, and geochronologic studies of displaced alluvial fans to place constraints on fault slip rate. Paleoseismic trenching will be performed in each study to assess earthquake timing and recurrence. Additionally, NBMG is performing reconnaissance studies of the Spanish Springs Peak and East Reno fault zones and evaluating unpublished legacy data to assess the potential of future study sites.

Inspection of the National Quaternary fault and fold database (NQFFD) indicates that at least 50 active faults occur in Nevada within approximately 100 km of the Reno/Carson/Lake Tahoe urban areas. For completeness, faults in California (9 faults) are also included in this compilation. Of the 50 faults in Nevada, the current National Seismic Hazard Map model only includes 24 sources. This is largely due to poorly constrained fault-source characterization for most of the faults including unknown paleoseismic histories and the lack of consensus slip-rate and recurrence-interval data. The 2014 update of the NSHM included adjustment of throw rate for 12 faults in Nevada, including 2 faults in the Reno focus area. These updates reflect recent research, much of which is not recorded in the NQFFD. During the Quaternary fault parameter compilation for this workshop, it was noted that a slip rate study along the Antelope Valley (Sarmiento et al., 2011) apparently was not considered in the 2014 update. New slip rate information is now available for the Pyramid Lake and West Tahoe-Dollar Point fault zones which could contribute towards refinement of parameters for these sources in the 2018 update (Angster et al., 2014; Pierce et al., 2017).

The list of faults shown in Table 1 serves as a starting point to discuss the current state of knowledge on Quaternary fault parameters and evaluate priorities for faults requiring additional study. I propose the following criteria as an initial qualitative assessment for prioritization of future fault research. This criteria and scoring method includes the following characteristics:

Included in the model (yes = 0, no = 1);
Length (<8km = 0, 8-25 km = 1, >25 km = 2)
Slip rate data quality (well constrained = 0, moderately constrained = 1, no data = 2)
Slip rate (<0.2 = 0, 0.2-1 = 1, 1-5 = 2)
Recurrence/timing data (yes = 0, no = 1)
Age of most recent deformation (older than latest Pleistocene = 0, latest Pleistocene = 1, <15 ka = 2)
Distance to Reno (>30 km = 0, <30 km =1)

It is anticipated that this workshop will produce a consensus method for future research prioritization. The intent is to update the list annually, as studies are completed along individual faults. Class B faults should be a low priority until more definitive evidence of activity is developed.

References

Angster, S., Huang, W., Wesnousky, S.G., Kent, G., Nakata, T. and Goto, H., 2014, Earthquake size and slip rate of the Pyramid Lake fault zone near Reno, Nevada, NEHRP Final Technical Report, G13AP00033, 22 p.

Bormann, J., (2013), New insights into strain accumulation and reléase in the central and northern Walker Lane, Pacific-North American plate boundary, California and Nevada, USA, Ph.D. dissertation, August 2013, University of Nevada, Reno.

Pierce, I.K., Wesnousky, S.G., and Owen, L.A., 2017, Terrestrial cosmogenic surface exposure dating of moraines at Lake Tahoe in the Sierra Nevada, California, and slip rate estimate for the West Tahoe fault, Geomorphology, 298, p. 63-71.

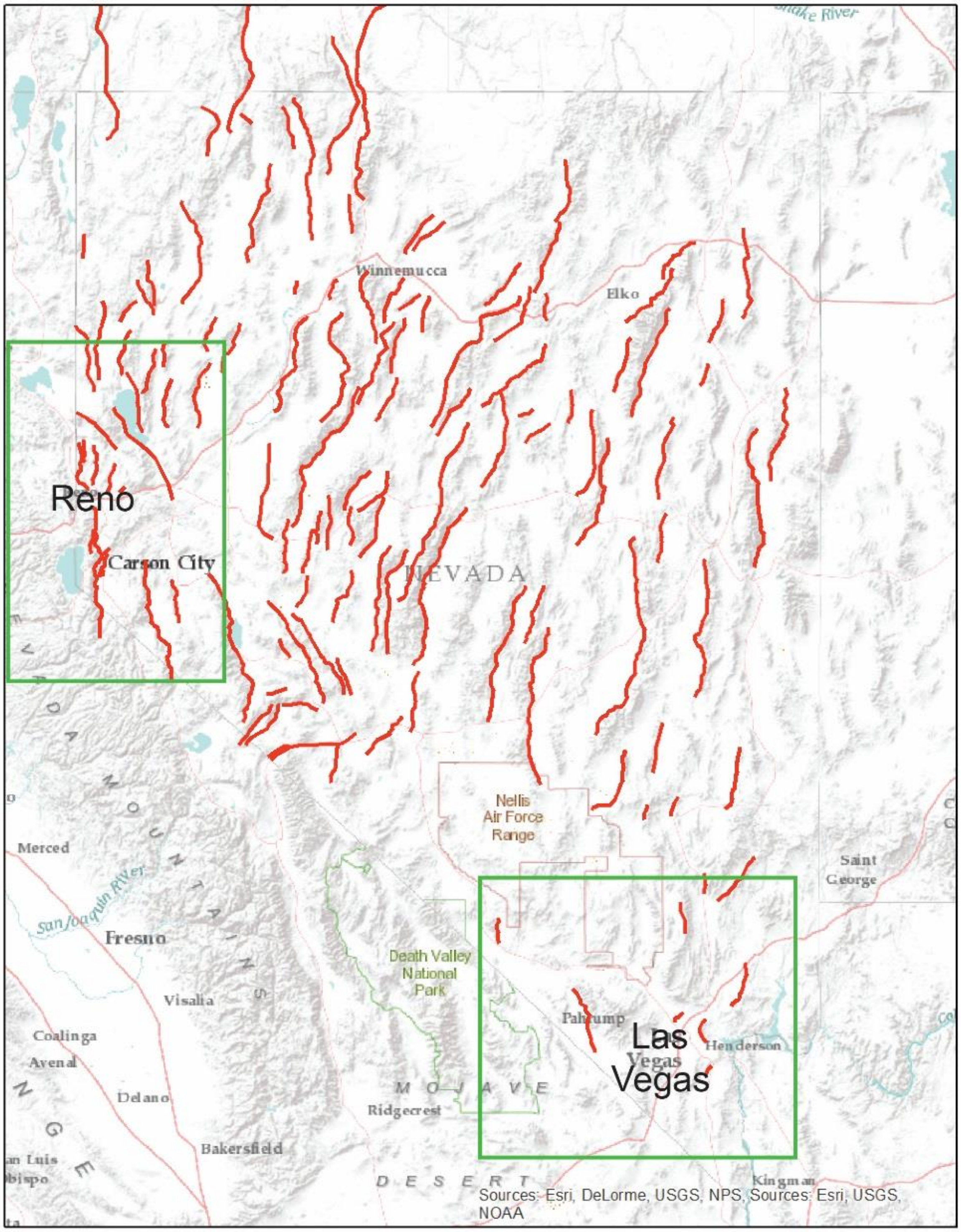


Figure 1. Map showing faults (red lines) included in the 2014 update of the National Seismic Hazard model. Quaternary fault parameters are compiled for the areas shown by green boxes including the Reno/Carson City/Lake Tahoe and Las Vegas urban areas.

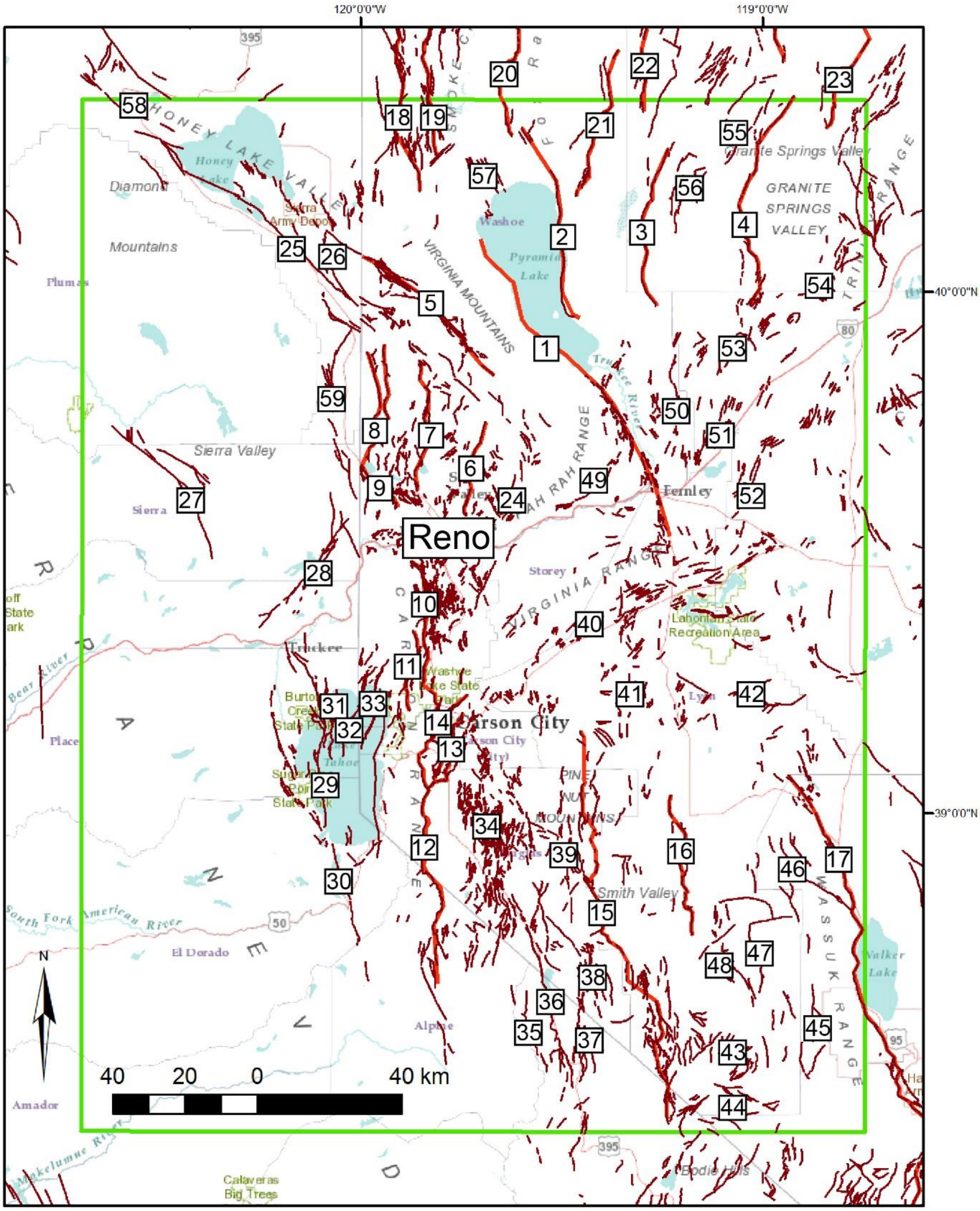


Figure 2. Map of the Reno/Carson City/Lake Tahoe focus area showing faults included in the National Seismic Hazards model (bold red lines) and active faults from the National Quaternary fault and fold database (thin maroon lines). Fault numbers correspond to Table 1.

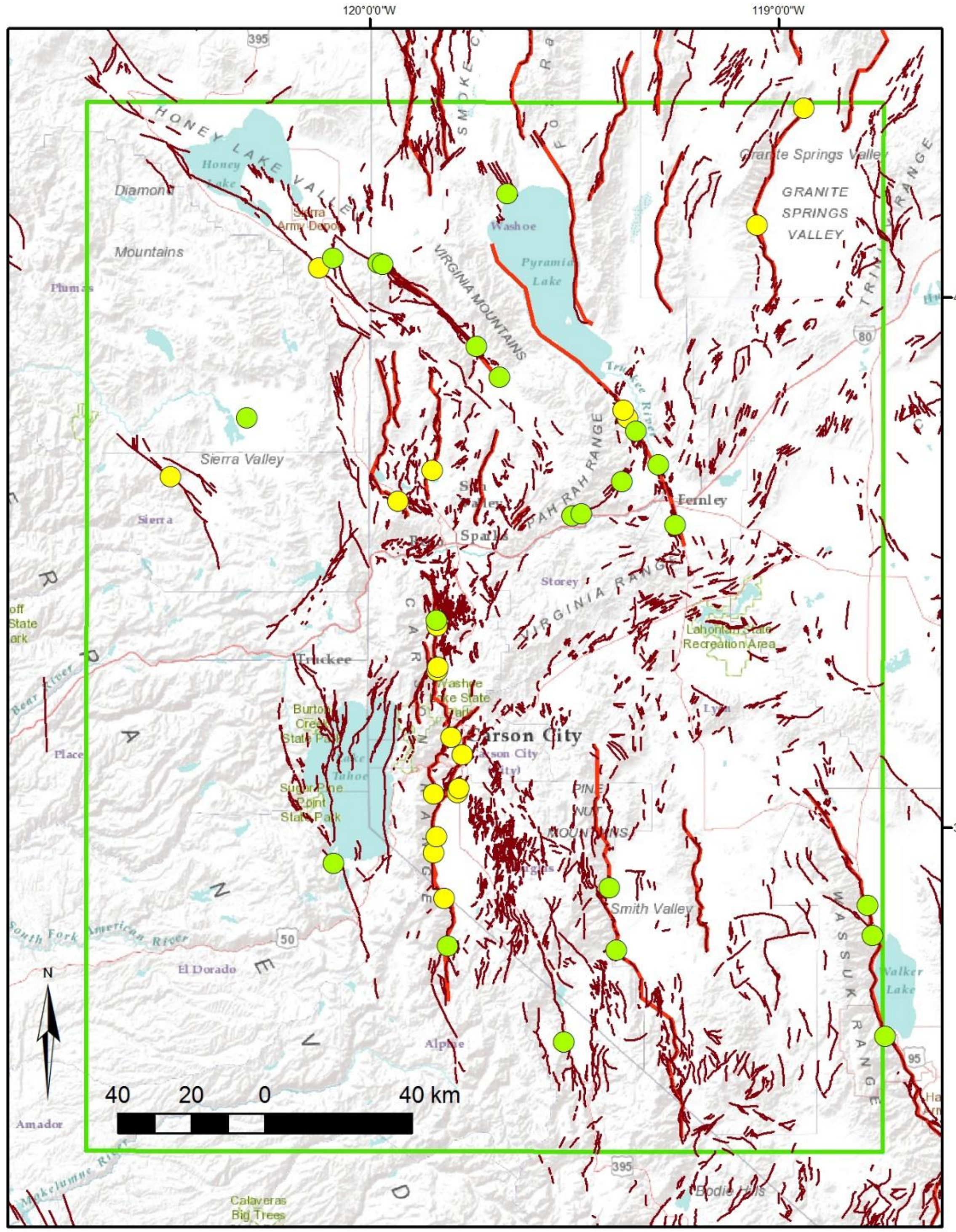


Figure 3. Map showing the distribution of paleoseismic studies that are recorded (yellow circles) and not recorded (light green circles) in the in the Quaternary fault and fold database.

Table 1. Faults within the Reno focus area.

Fault number	Fault name	geologic slip rate (mm/yr) QFF	Geologic slip rate (mm/yr) NSHM	Timing data	length (km)	Most recent activity	Comment and Score based on qualitative criteria defined in this presentation.
INCLUDED IN NSHM							
1	Pyramid Lake fault zone	1-5	2	Yes	77	<15	
2	Eastern Pyramid Lake/Lake Range fault zone	<0.2	0.131	no	44	<130	
3	Nightingale Mountains fault zone	<0.2	0.131	no	35	<1600	
4	Granite Springs Valley fault zone	0.2-1	0.261	yes	50	<15	
5	Warm Springs Valley fault zone	<0.2	0.5	yes	70	<15	
6	Spanish Spings Valley fault zone	<0.2	0.131	no	23	<15	
7	Freds Mountain fault	<0.2	0.131	yes	28	<130	
8	Petersen Mountain fault	<0.2	0.131; 0.065	no	25	<130	
9	Peavine Peak fault zone	<0.2	NA	yes	15	<15	
10	Mount Rose fault zone	1-5	1.958	yes	38	<15	
11	Little Valley fault	0.2-1	0.261	yes	17	<15	
12	Carson Range-Kings Canyon fault (Genoa fault)	1-5	2.61	yes	36	<15	
13	Indian Hill fault	<0.2	0.131	yes	8	<15	
14	Carson City fault	<0.2	0.131	yes	16	<15	
15	Smith Valley fault	<0.2-1	0.326	yes	96	<15	
16	Singatse Range fault zone	<0.2	0.131	no	40	<130	
17	Wassuk Range fault zone	0.2-1	0.914	yes	116	<15	
18	Dry Valley-Smoke Creek Ranch fault zone	<0.2	0.131	no	48	<15	
19	Bonham Ranch fault zone	0.2-1	0.261	no	54	<15	
20	Fox Range fault zone	<0.2	0.131	no	31	<15	
21	San Emidio fault zone	0.2-1	0.261	yes	32	<15*	*New age (Ramelli)
22	Selenite Range fault zone	<0.2	0.131	no	18	<1600	
23	Seven Troughs Range fault zone	<0.2	0.131	no	37	<1600	
24	Spanish Springs Peak fault zone	<0.2	0.1	no	13	<1600	
NOT INCLUDED IN 2014 NSHM							
25	Honey Lake fault zone	1-5		yes	98	<15	CA
26	Fort Sage fault	<0.2		yes	17	<15	CA
27	Mohawk Valley fault zone	0.2-1		yes	42	<15	CA
28	Dog Valley fault zone	NA		no	28	<1600	CA
29	West Tahoe-Dollar Point fault zone	0.2-1		yes	51	<15	CA
30	Tahoe-Sierra frontal fault zone	NA		no	50	<1600	CA
31	Agate Bay fault	NA		no	17	<1600	CA
32	North Tahoe fault	0.2-1		no	25	<15	CA and NV
33	Incline Village fault	0.2-1		yes	20	<15	
34	East Carson Valley fault zone	<0.2		no	48	<15	
35	Slinkard Valley fault zone	NA		no	25	<130	CA
36	Antelope Valley fault zone	0.2-1		yes	12	<15	CA and NV
37	East Antelope Valley fault zone	<0.2		no	18	<15	CA and NV
38	Unnamed faults west of Wellington Hills	<0.2		no	28	<1600	

Fault number	Fault name	geologic slip rate (mm/yr) QFF	Geologic slip rate (mm/yr) NSHM	Timing data	length (km)	Most recent activity	Comment and Score based on qualitative criteria defined in this presentation.
NOT INCLUDED IN NSHM							
39	Unnamed faults in the Pine Mountains	<0.2		no	42	<1600	
40	Carson lineament	<0.2		no	72	<15	
41	Unnamed fault zone in Pine Mountains	<0.2		no	18	<1600	
42	Unnamed fault zone in Desert Mountains	<0.2		no	30	<1600	
43	Unnamed fault zone in Pine Grove Hills	<0.2		no	21	<1600	
44	Unnamed faults near East Walker River	<0.2		no	29	<1600	
45	Unnamed faults west of Pike Peak	<0.2		no	20	<1600	
46	Unnamed faults west of Wassuk Range	<0.2		no	24	<130	
47	Cambridge Hills fault	<0.2		no	15	<1600	
48	Unnamed fault zone near Pine Grove Flat	<0.2		no	33	<1600	
49	Olinghouse fault zone	<0.2		yes	18	<15	
50	Unnamed fault zone near Little Valley	<0.2		no	26	<1600	
51	Unnamed fault zone southeastern Truckee Range	<0.2		no	34	<15	
52	Hot Springs Mountain fault zone	<0.2		yes	43	<15	
53	Unnamed fault zone near North Valley	<0.2		no	17	<1600	
54	Unnamed fault zone on northwest side of Trinity Range	<0.2		no	34	<15	
55	Unnamed fault zone along Sahwave Mountains	<0.2		no	14	<1600	
56	Unnamed fault zone between Kumive and Sage Hen Valleys	<0.2		no	17	<130	
57	Terraced Hills fault zone	<0.2		yes	13	<15	Age from Vice, 2008
58	Unnamed faults in Susanville-Eagle Lake area	NA		no	20	<1600	CA
59	Last Chance/Upper Long Valley fault zone	NA		no	33	<15	CA and NV

The Search for strike-slip in the Northern Walker Lane: New slip rates and characterization of active faults in Antelope, Mason, and Smith valleys, Nevada

Pierce, I.K.D.[1], Wesnousky, S.G.[1], and Owen, L.A.[2]

[1]Center for Neotectonic Studies and Seismological Laboratory, University of Nevada, Reno, NV 89557, USA

[2]Department of Geology, University of Cincinnati, Cincinnati, OH 45221, USA

Antelope, Mason and Smith Valleys are half-grabens within the Northern Walker Lane, east and south of Carson City and Reno, Nevada. We apply recently acquired 0.5-1 m/pixel lidar data and terrestrial cosmogenic nuclide (TCN) surface exposure ages to characterize the geometry, Quaternary expression, and slip rates of active faults in these three valleys. Antelope Valley hosts a very active rangefront fault with numerous uplifted and faulted alluvial fans and stream terraces along the western margin of the basin. There are several locations along the rangefront where stream terraces appear to be right-laterally displaced. Above the town of Walker, CA at the southwestern edge of the basin is an ~30 m high fault scarp, which displaces sediments dated with Cl-36 to ~50 ka. This suggests a vertical displacement rate of ~0.6 m/yr, about half of recent geodetic estimates. The majority of the rangefront fault in Mason Valley forms an alluvial-bedrock contact, and displays only one site where the active rangefront fault has cut and displaced older fan sediments. TCN ages of a ~10 m vertically faulted alluvial fan surface at this site are >100 ka, suggesting a <0.1 mm/yr vertical slip rate for the range bounding fault, significantly less than geodetic estimates. The new lidar data reveal several lineaments in the southernmost portion of the valley that display measurable right-lateral displacements. Analysis of lidar in Smith Valley shows a much more active range front fault than that of Mason Valley, with frequently offset late Quaternary fan surfaces along the northern half of the range, along with two additional previously unmapped northwest striking fault segments towards the center of the basin, that also offset Holocene sediments. The Artesia Fan along the Smith Valley rangefront is offset ~10 m, and TCN ages range from 10-30 ka, leading to a vertical slip rate of 0.33-1.0 mm/yr. The rate in this case appears to be in line with geodetic rates of deformation that have been reported by others.

New estimates on the rate of slip for faults of the Central Walker Lane, Nevada

Angster, S.[1], Wesnousky, S.G.[1], Owen, L.[2], Figueiredo, P.[2], Hammer, S.[2], and Cesta, J.[2]

[1]Center for Neotectonic Studies, University of Nevada, Reno, 1664 N. Virginia St., Reno, NV.

[2]Dept. of Geology, University of Cincinnati, 2600 Clifton Ave., Cincinnati, OH 45221

The Walker Lane shear zone trends northwest along the eastern Sierra Nevada and accommodates a significant portion of North American-Pacific Plate relative transform motion. In the central portion of the Walker Lane, the Benton Springs, Petrified Springs, Gumdrop Hills, and Indian Head faults have been identified as the main Quaternary active strike-slip faults that accommodate some portion of the geodetically observed ~8 mm/yr of northwest directed transtensional dextral shear measured across the region. We place quantitative geologic constraints on the shear and extensional components of slip determined from Quaternary mapping of high-resolution topographic datasets, including lidar and structure-from-motion, and ^{10}Be and Cl^{36} cosmosgenic nuclide dating and soil characterization of offset alluvial fans along each of the main strike-slip faults of the central Walker Lane. Thus far, results yield late-Pleistocene-Holocene strike-slip rates for the Benton Springs, Gumdrop Head, and Indian Head faults of 1.8 ± 0.6 mm/yr, 0.6 ± 0.4 mm/yr, and <0.9 mm/yr, respectively, and we are awaiting results for the Petrified Springs fault. The extensional component of slip appears to be minimal for these faults, with a maximum determined rate of 0.12 mm/yr on the Benton springs fault, assuming a minimum dip of 60^0. Thus far, the horizontal rates agree with prior geologic estimates and are at the high end of rates predicted by others from geodetic block modeling. These observations suggest steady rates of shear across these sets of faults throughout the Quaternary within this portion of the Walker Lane.

Recent Paleoseismicity of the Kings Canyon Fault Zone between Ash and Vicee Canyons, Carson City, Nevada

Craig M. dePolo[1], Ryan Gold[2], Rich Briggs[2], Anthony Crone[2], Shannon Mahan[2], and Glenn Borchardt[3]

1 Nevada Bureau of Mines and Geology
2 United States Geological Survey
3 Soil Tectonics

The 15 km long, north-trending, east-dipping, normal dip-slip Kings Canyon fault zone is part of the Carson Range fault system and is located <5 km from downtown Carson City, Nevada. Previous investigations have documented Holocene faulting on this structure, but lacked absolute age control. To determine the recent rupture history of the Kings Canyon fault zone, we excavated three trenches and a soil pit into a late Quaternary alluvial fan cut by numerous fault traces near Ash Canyon.

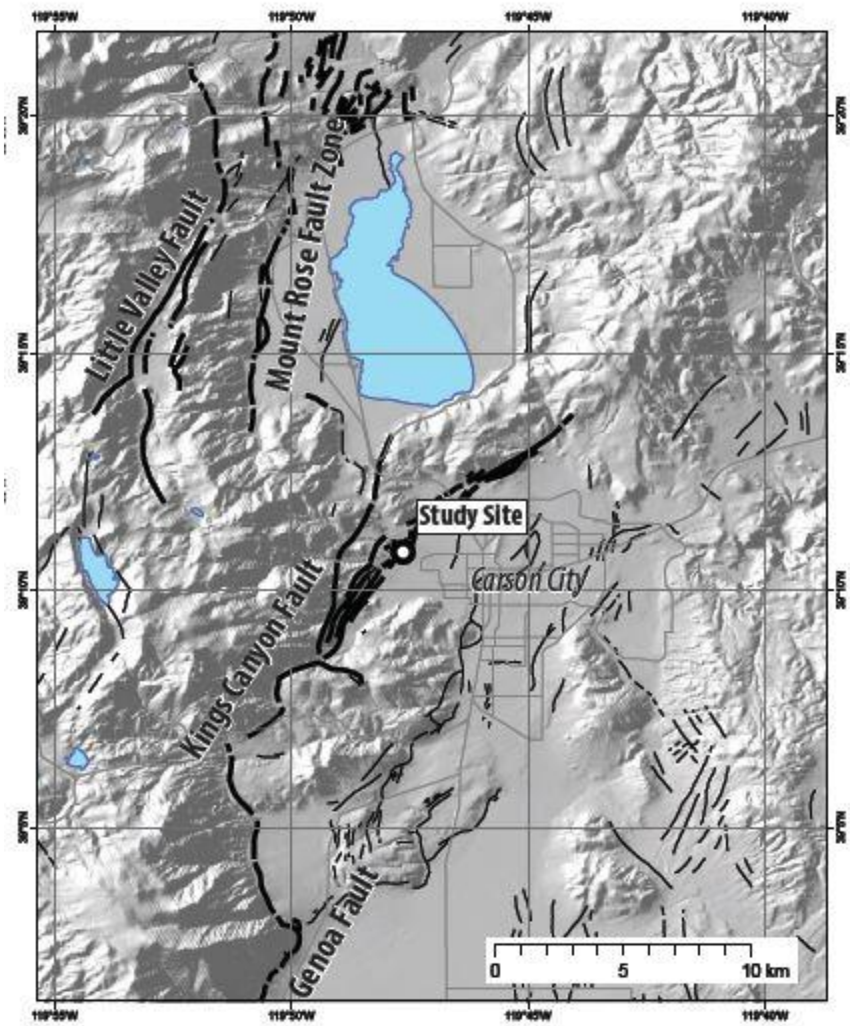


Figure 1. Location map of the Kings Canyon fault zone and the study site.

The alluvial fan deposits are generally cobbly coarse-and-medium-grained granitic sands, with a few boulders, as much as 60 cm in diameter. Sedimentary structure varied from thin, regular well-bedded sand layers and lenses to massive cobbly coarse sand layers as much as 0.5 meter thick. A compound soil was found in at the site consisting from bottom to top of alluvial fan deposits with thin sub-horizontal clay seams, a silica-cemented Bq horizon, a weakly colored Bw horizon, and an organic rich, fine sand A horizon. This study found that the moderate silica-cement in the Bq horizon appears to have formed during the last ~2000 years.

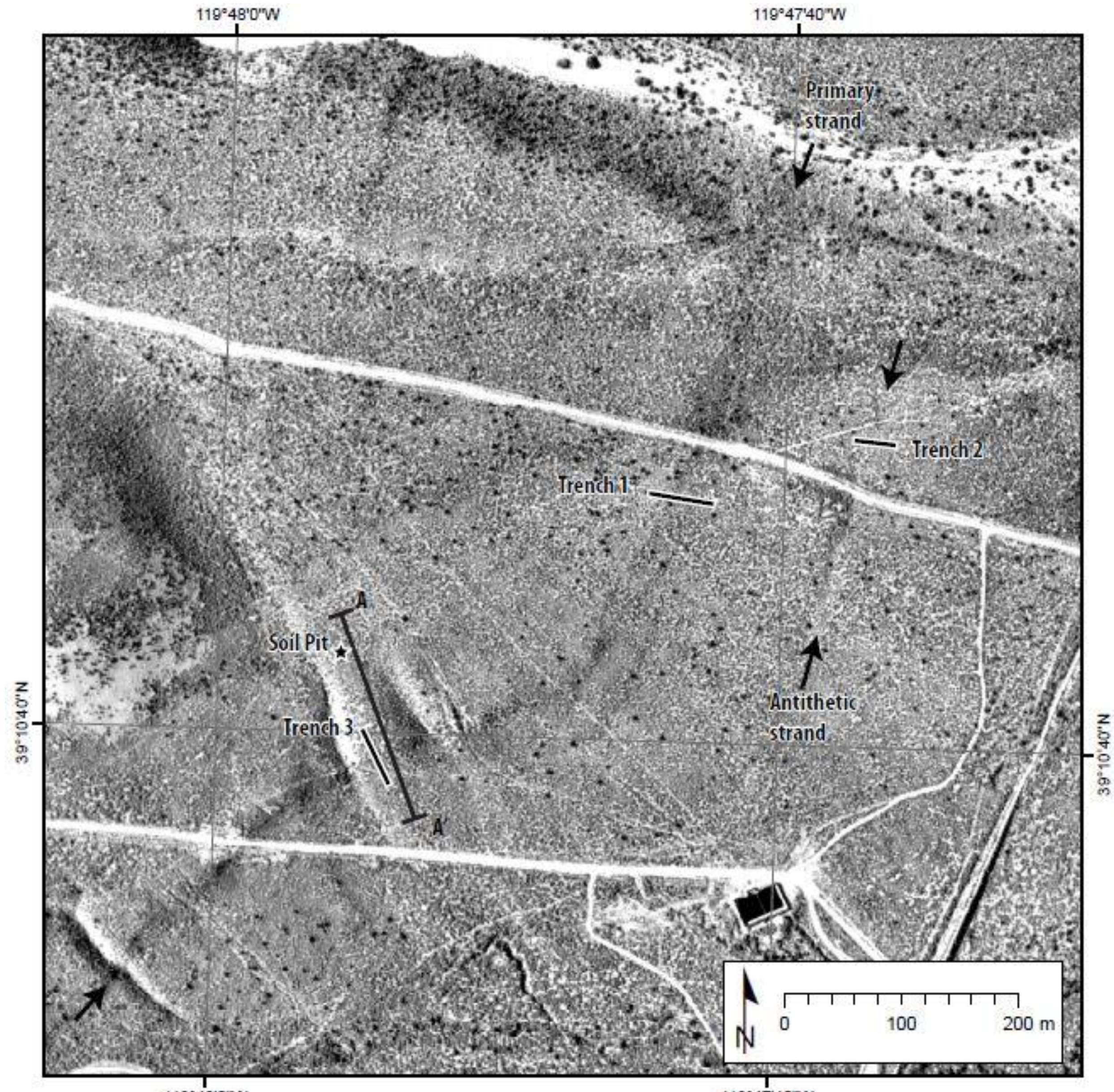


Figure 2. Low-sun-angle photograph flown in 1972 by Dr. David "Burt" Slemmons showing the youngest strands of the Kings Canyon fault zone in fan deposits (a main fault trace and an antithetic fault trace) and the locations of Trenches 1, 2, and 3, the soil pit, and scarp profile A-A' partially shown in Figure 4.

Based on the exposure in Trench 3, sited across the base of a large northeast-striking, beveled fault scarp, we document evidence for four surface-faulting earthquakes based on colluvial-wedge stratigraphy, fault terminations, and aligned gravels indicating periods of slope stability between earthquakes. Additional supporting evidence of these events comes from Trenches 1 and 2. Ages from eight AMS radiocarbon and ten optically stimulated luminescence samples provide constraints on the timing of the four paleoearthquakes. Oxcal modeled ages using these dates are Paleoearthquake 1 (PE1) at 1420 ±70 cal. ybp, PE2 at 1630 ±110 cal. ybp, PE3 at 1820 ±140 cal. ybp, and PE4 at 3960 ±820 cal.ybp. These data imply that the three most recent events occurred as a cluster of earthquakes, with short interseismic intervals of approximately 200 to 300 years.

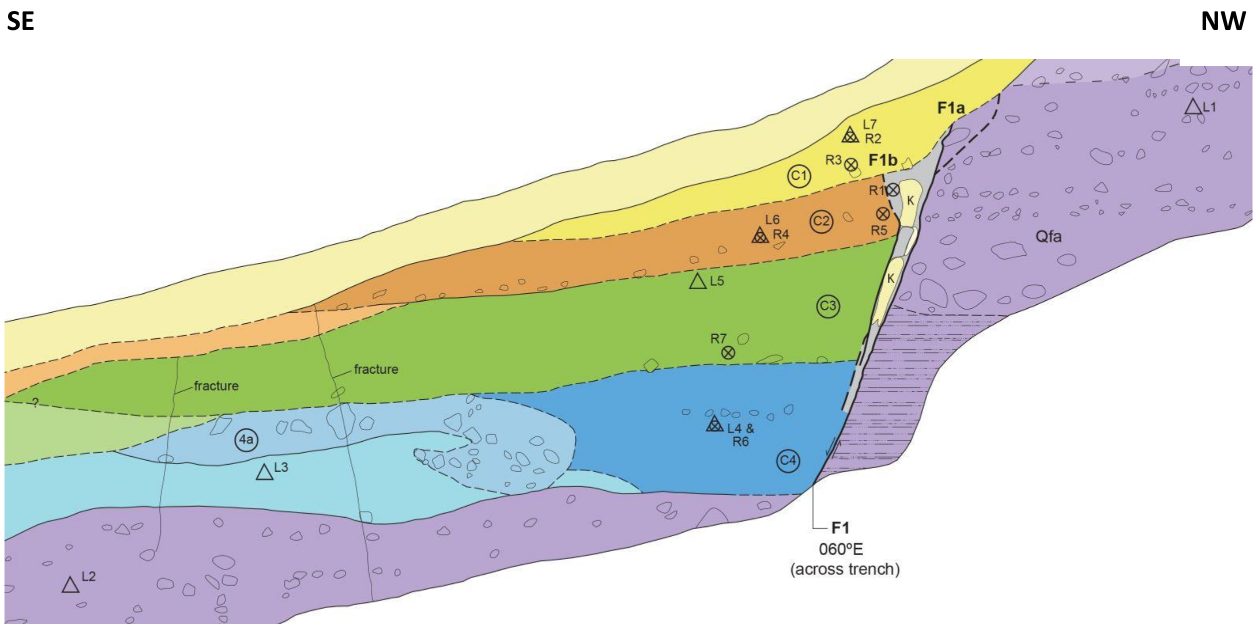


Figure 3. The central part of Trench 3 showing the colluvial wedge stratigraphy (C1 through C4) and the location of radiocarbon dates (circles) and luminescence dates (triangles). “k” are krotovina.

A late Holocene vertical fault slip rate for the Kings Canyon fault of 1.5 to 1.7 m/ky since 5 ka was calculated by combining the vertical surface offset recorded at Trench 3 (8.4 ±0.5 m) with the age of the faulted fan below this surface (~5 ka, based on luminescence dating). During the late Holocene, this fault slipped at a rate comparable to the Genoa fault, south along the range front.

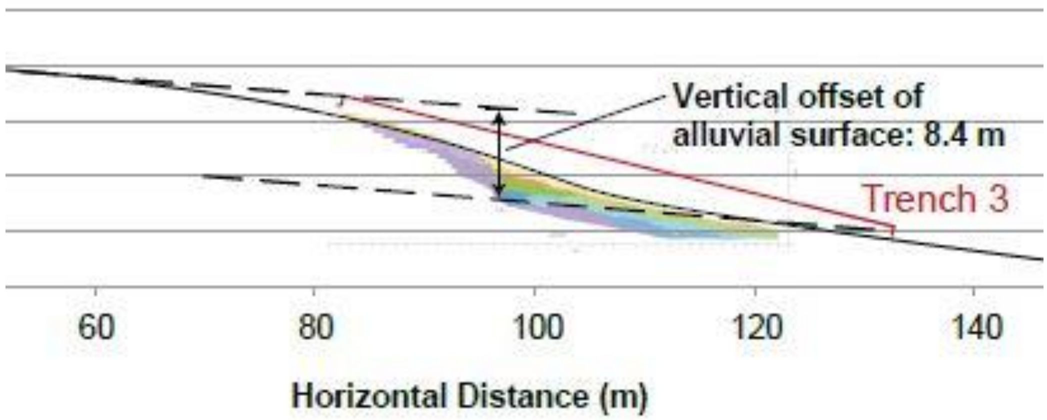


Figure 4. Central part of the scarp profile at Trench 3 illustrating the 8.4 m offset of the alluvial fan surface. The uncertainty on this estimate is ±0.5 m.

This paleoseismic history allows us to evaluate synchronicity between the Kings Canyon fault and adjacent faults in the Carson Range fault system. Ramelli and Bell (2014) estimate that the two most-recent events along the Genoa fault occurred about 300 ybp and about 1700 ybp.
The Kings Canyon fault did not fail during the most-recent earthquake along the Genoa fault. There are two paleoearthquakes along the Kings Canyon fault (PE2 or PE3) that might correlate with the penultimate event along the Genoa fault. There is a similar paleoseismic relationship between the Kings Canyon fault zone and the Washoe Valley fault zone to the north. However, the youngest event on the Kings Canyon fault zone does not correlate with any adjacent events, and thus was an independent rupture.

Our observations suggest the Kings Canyon fault zone poses a significant seismic hazard to the Reno-Carson City urban corridor and potentially the northern Tahoe basin. The fault zone has produced four surface-rupturing earthquakes during the last half of the Holocene, and the elapsed time since the most recent event is 1400 years. While the Kings Canyon fault zone fails as an independent source, it also might fail along with adjacent faults along the range front. Results from this investigation indicate that the Kings Canyon fault zone has produced earthquakes with Mw >6.8.

Fault interactions along a N-S belt around 114.75 degrees W longitude in southern Nevada

Wanda J. Taylor[1], Shaimaa Abdelhaleem[1], Alexander Peck[1], Seth Dee[2], and Craig dePolo[2]

[1] Department of Geoscience, University of Nevada Las Vegas, 4505 Maryland Parkway, Las Vegas, NV 89154-4010
[2] Nevada Bureau of Mines and Geology, University of Nevada, Reno/178, Reno, NV 89557

A series of Quaternary faults that contribute to the regional Quaternary strain budget, but lack detailed study, lie in a N-S belt along 114.75°W longitude in southern Nevada. These faults have spatial relations that suggest structural interactions are probable, and thus, related slip events among them are possible. From S to N the faults are: the Frenchman Mountain (FMF), California Wash (CWF), Arrow Canyon Range, Wildcat Wash, Kane Spring Wash, Coyote Spring, and Maynard Lake faults. We have and are collecting map, paleoseismic, and scarp data as well as information on the related basins to address the histories and inter-relations of these faults. The Frenchman Mountain fault was active in both the Miocene and Quaternary. It has a total of ~7 km of stratigraphic separation based on Triassic units exposed in the footwall and logged in wells in the hangingwall. The maximum hangingwall Miocene-Quaternary basin-fill thickness is ~4.7 km based on gravity data (Langenheim et al., 2001, Tectonics). Kinematic indicators show that the FMF has dip slip near the center, which changes to oblique slip as the fault curves to the N and S. To the north in Nellis Dunes Recreation Area, the slip is normal left-oblique and largely NE-striking left-lateral strands offset structures associated with the, thus, older Las Vegas Valley shear zone. The FMF tip underlaps the CWF tip, which steps toward it thorough a series of right steps. The CWF is a predominantly normal fault and bounds a basin with up to ~2.5 km of Oligocene-Quaternary fill. Where the scarps along the CWF are in older Quaternary deposits, multi-vent scarps are as much as 7 m high, but the youngest scarps in the youngest deposits are a maximum of 1-2 m. Two colluvial wedges exposed in a natural dissection yielded ^{14}C ages of 1825 ± 95 and 1950 ± 80 cal yr BP. The CWF tip overlaps with that of the Arrow Canyon Range fault, another normal fault, with a fault spacing of ~25 km. At the northern end, the Arrow Canyon Range fault forms a gentle relay ramp, exposed in Miocene and Quaternary sediments, with the southern Wildcat Wash fault. A natural dissection along the Wildcat Wash fault exposed two colluvial wedges, one of which yielded a ^{14}C date on charcoal of 1445 ± 85 cal yr BP. Northward the ~N-striking Wildcat Wash fault curves to a NE-strike as it approaches the NE-striking left-lateral Kane Spring Wash fault. The Kane Spring Wash fault lies along the southern edge of the Southern Nevada seismic belt. To the north, the N-striking, normal Coyote Spring fault scarp extends for about 18 km and the maximum width of the associated basin is only ~3 km. The Coyote Spring fault spans most of the gap between the left-lateral Kane Spring Wash fault and the left-lateral NE-striking Maynard Lake fault to the north. The Maynard Lake fault shows left offsets of older Quaternary drainages, offset of a young resurgent fan and the central part contains a transpressional right stepover. In summary, the curves in strikes of some of these faults toward each other near their tips, the relay ramp, and the proximity of these faults to each other suggest that they may work together or in sequence to accommodate regional strain. The NE-striking left-lateral faults and fault sections probably accommodate slip transfer.

New paleoseismic data from the Frenchman Mountain fault, Las Vegas

Seth Dee, Craig dePolo, Wanda Taylor, and Shannon Mahan

The Frenchman Mountain fault is an 18-km long, north- and northeast-striking, west-dipping, range-bounding normal fault on the eastern side of Las Vegas Valley. The fault is expressed along the western flank of Frenchman and Sunrise Mountains as a zone of sub-parallel scarps in alluvial fan surfaces, bedrock range front scarps, and exposed shear planes juxtaposing coarse grained Quaternary sediments against Precambrian and Paleozoic footwall rocks (Matti, et al., 1993; Anderson and O'Connell, 1993; Peck, 1997). The Frenchman Mountain fault is assigned a vertical slip rate of 0.015 mm/yr in the USGS National Seismic Hazard Map (Peterson et al., 2008, 2014), and geodetic block modeling suggests the fault has a 0.2 mm/yr normal slip rate (Hammond et al., 2014). Evidence for Quaternary paleoearthquakes has previously been presented (Anderson and O'Connell 1993; and Rittase, 2007; and Peck, 1997), but these studies did not include detailed documentation of paleoseismic evidence, age dating of deposits, estimates of earthquake recurrence or late-Quaternary slip rate.

A previously excavated exposure of the Frenchman Mountain fault in Quaternary sediments was recently identified and investigated in detail. The excavation was originally part of a fault investigation conducted between 2005 and 2007 by a local consulting company for a planned housing development; the consultant's report remains confidential. The fault exposed in the excavation is buried by late-Pleistocene alluvial fan deposits, but the exposure is on strike with Quaternary fault scarps to the north and south that are 2-8 m high.

Our new detailed logging of the excavation documents evidence for three paleoearthquakes on an 85° west-dipping fault zone in Quaternary alluvial fan gravels. Evidence for these events includes offset stratigraphy and three scarp derived colluvial wedge packages. Optically stimulated luminesce (OSL) dating samples were collected from all colluvial wedge packages, the faulted stratigraphy beneath the wedge and the overlying unfaulted fan gravels; results of the OSL dating are pending. Quaternary units beneath the colluvial wedge packages have an average, total vertical displacement of 1.6 m across the fault zone. The oldest recorded faulting event (E3) has an estimated vertical displacement of 0.8 m. The two youngest events (E1 and E2) have a combined vertical displacement of 0.8 m.

An adjacent excavation, 65 m to the east, exposes a 35° west-dipping fault zone with well-developed fault gouge, placing older Quaternary alluvial fan gravels (early Pleistocene?) against Precambrian gneiss. The relationship between the two fault zones at depth is unresolved, but it is likely that the high-angle fault soles into the lower angle fault at an estimated intersection depth of 50 m below the ground surface.

A basin depth map of the Las Vegas Valley, inverted from gravity data, shows the deepest part of the basin is parallel to, and west of the Frenchman Mountain range front (Langenheim et al, 2001; Langenheim et al, 2005). The gravity data suggests that the Las Vegas basin is bound on the east by a 60°-65° west dipping fault that projects to the surface over 800 m west of the logged fault exposure. If the inferred basin bounding fault at depth connects to the lower angle fault at the range front it suggests an active normal fault with a convex-up or anti-listric orientation.

The Las Vegas Valley Fault System – A 2017 Progress Report

Craig M. dePolo[1], Wanda J. Taylor[2], Seth M. Dee[1], Shaimaa Abdelhaleem[2], James L. Werle[3]

1. Nevada Bureau of Mines and Geology
2. Geoscience Department, University of Nevada, Las Vegas
3. Nova Geotechnical

The Las Vegas Valley fault system (LVVFS) is made up of five recognized faults: the Eglington fault, Decatur fault, Valley View fault, Cashman fault zone, and Whitney Mesa fault zone (fig.1). In addition, there are many smaller faults between and as strands of the larger faults. Faults within the LVVFS are expressed at the surface as fault scarps and warps, springs and spring deposits, and vegetation and tonal lineaments. The faults are closely spaced, subparallel to one another, and have the same sense of displacement, normal dip-slip with a down-to-the-east component. The faults are generally north-south striking in the central part of the basin and northeast striking in the northern part of the basin. Multiple hypotheses have been proposed for the origin of the fault scarps including tectonic movement, differential compaction, spring discharge deposits, salt dissolution, shaking-induced settlement, and various combinations of these. The Nevada Bureau of Mines and Geology, the Department of Geology at the University of Nevada Las Vegas, and the U.S. Geological Survey have launched a multi-year research project to understand the seismic potential of these faults. Evidence that supports a seismic potential in Las Vegas Valley include: recorded earthquake activity (including some small felt earthquakes; fig. 2), documented brittle surface fault offsets, and evidence of potential liquefaction features.

Figure Reference:

Page, W.R., Lundstrom, S.C., Harris, A.G., Langenheim, V.E., Workman, J.B., Mahan, S.A., Paces, J.B., Dixon, G.L., Rowley, P.D., Burchfiel, B.C., Bell, J.W., and Smith, E.I., 2005, Geologic and geophysical maps of the Las Vegas 30′ x 60′quadrangle, Clark and Nye counties, Nevada, and Inyo County, California: U.S. Geological Survey Scientific Investigations Map 2814, scale 1:100,000.

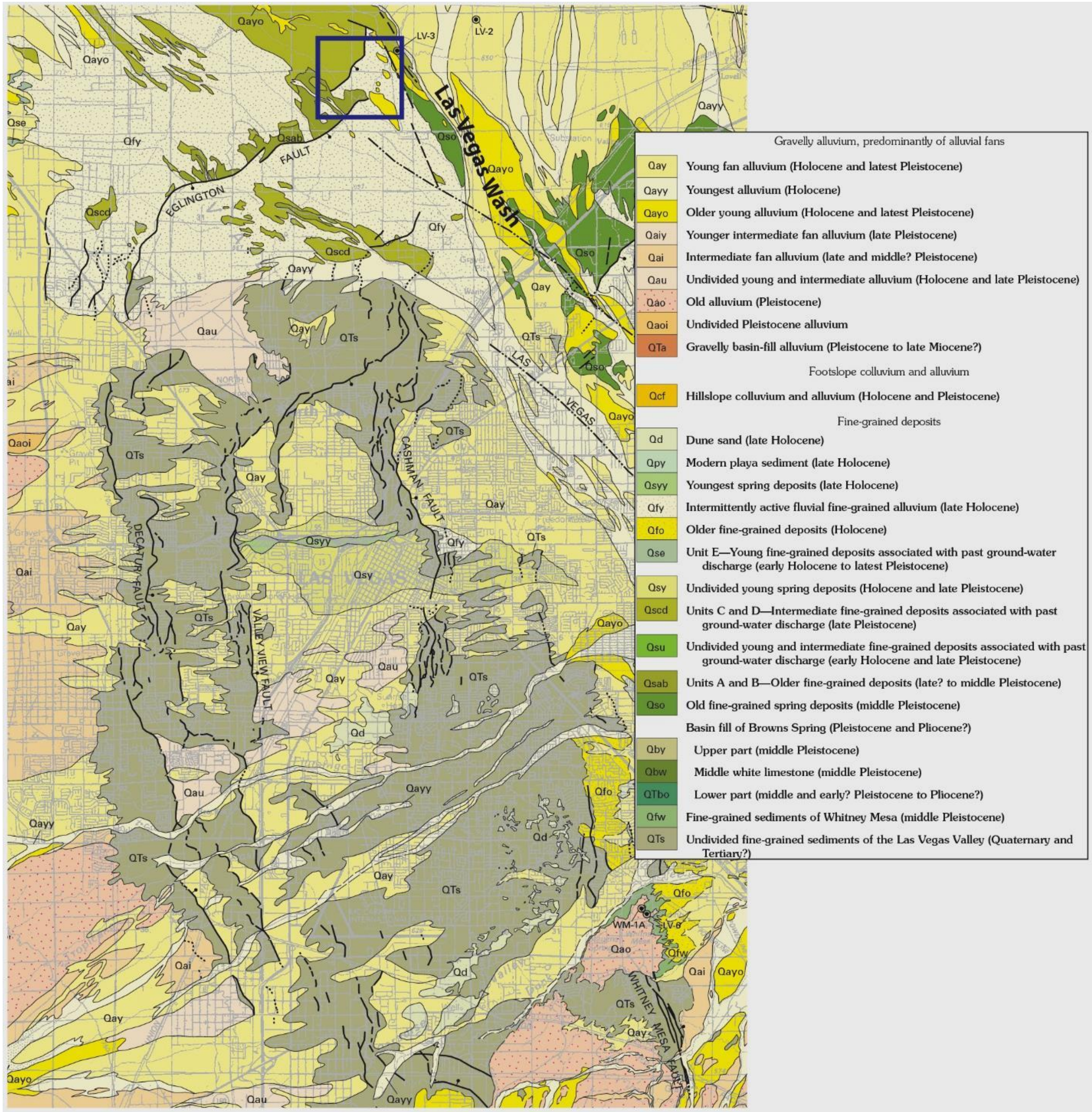


Figure 1. Geologic map and Quaternary faults in the central part of Las Vegas Valley. Blue box denotes an area of future trenching by this project. The map is a part of a larger map created by Page et al. (2005).

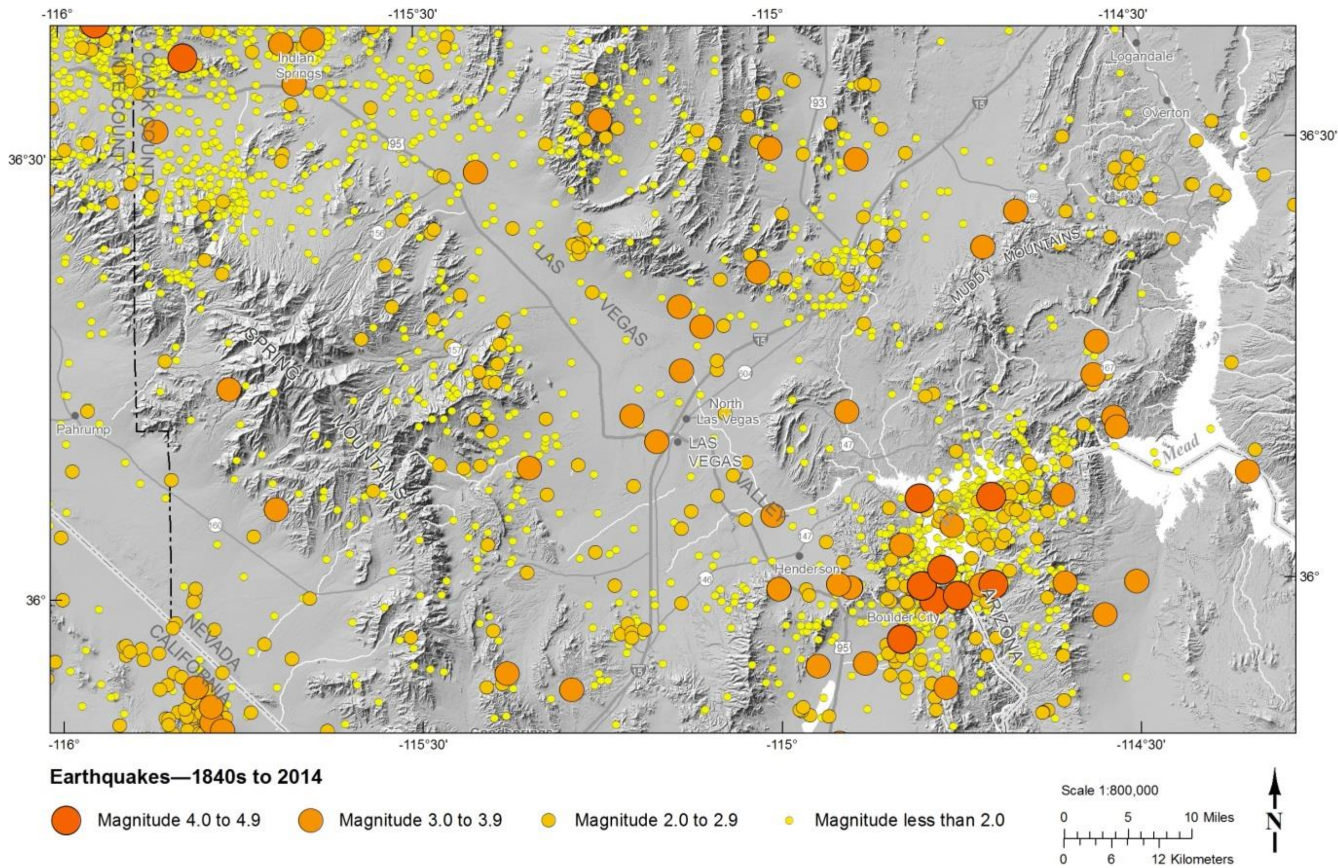


Figure 2. Earthquake activity in the Las Vegas Valley region between the late 1800s and 2014. Las Vegas Valley is in the center of the figure and many micro-earthquakes are located in and around the valley. Post 1970 activity was recorded by the Nevada Seismological Laboratory.

Seeking input on the inclusion of the Eglington fault, Nevada, in the National Seismic Hazard Map

Gold., R.[1], Briggs, R.[1], dePolo, C.[2], Dee, S.[2], and Petersen, M.[1]

[1] U.S. Geological Survey, Golden, Colorado

[2] Nevada Bureau of Mines and Geology, Reno, Nevada

The USGS seeks guidance from the Working Group on Nevada Seismic Hazards on treatment of the Eglington fault and other faults of the Las Vegas Valley fault system (LVVFS), Nevada, in future updates of the National Seismic Hazard Map (NSHM). The Eglington fault was first included as a seismic source in the 2014 update to the NSHM (Petersen and others, 2014), guided largely by a white paper published by the Nevada Bureau of Mines and Geology (dePolo and others, 2013). However, substantial uncertainty remains regarding the seismogenic potential of the LVVFS. Two endmember hypotheses have been proposed regarding the mechanisms responsible for producing the escarpments associated with the LVVFS, including the Eglington fault: 1) tectonic (e.g., coseismic surface rupture) and 2) non-tectonic (e.g., prehistoric differential sediment compaction). In this presentation, we will summarize existing geologic, geodetic, geophysical, and geochronologic data that provide insight into the mechanism(s) responsible for scarp formation within the LVVFS, point out unresolved problems with both endmember tectonic and non-tectonic scenarios, and describe ongoing work to address these problems. We will explore how to represent the Eglington fault within a logic tree framework for future map updates. Our ultimate goal is to seek a recommendation from the Working Group on Nevada Seismic Hazards regarding treatment of the Eglington fault and other faults of the LVVFS in future updates to the NSHM.

dePolo, C.M., Taylor, W.J., and Faulds, J.E., 2013, Evidence for high contemporary slip rates along the Eglington fault, Clark County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 13-12, 8 p.

Petersen, M.D. and others, 2014, Documentation for the 2014 update of the United States national seismic hazard maps: U.S. Geological Survey Open-File Report 2014–1091, 243 p.

Abstracts
Day 2, February 6, 2018

Review of Nevada and Eastern California Seismicity and the Nevada Seismic Network

Ken Smith, Rachel Hatch, Christine Ruhl, Graham Kent, Annie Kell, Dave Slater, Gabe Plank, Mark Williams, Mickey Cassar, Tom Rennie, John Torrisi, and Ryan Presser

The Nevada Seismological Laboratory (NSL) provides seismic network coverage and real-time seismic monitoring for the State of Nevada and areas of eastern California. Recent upgrades to the network have improved catalog completeness and the detection threshold throughout most of the state and region. With improvements to the network and processing procedures, NSL is now locating about 15K-18K earthquakes per year; however, most of state remains poorly monitored. Recent instrument installations in the Reno-Carson-City-Lake Tahoe-Truckee areas have improved overall data quality and coverage, greatly improving the ability to conduct detailed studies of local earthquake activity. Also, under support from U.S. Geological Survey's Earthquake Early Warning Program (EEW) the Nevada Seismological Laboratory is installing low-latency strong motion instrumentation along the eastern Sierra, with data incorporated into the west coast 'ShakeAlert' system. Recent station installations in the vicinity of the Nevada National Security Site have improved the catalog in Southern Nevada; whether these remain permanent stations is uncertain. Recent support from the USGS to install free-field broadband/strong motion instrumentation in the Las Vegas area will greatly improve completeness, location accuracy and earthquake response for the Las Vegas basin (site selection and permitting are underway). Other contributions to this meeting will provide details of recent research activities into earthquake processes and ground motion studies. Here we summarize Nevada historical earthquake activity and historical instrumental seismicity, most of which has been incorporated in prior hazard maps, and update the working group on the current state of the monitoring network, earthquake response, existing programs that contribute to seismic hazard evaluations and review the region's most recent earthquake activity.

Characterizing Earthquake Sources in the Urban Reno-Carson-Lake Tahoe Regions

Christine J. Ruhl, Kenneth D. Smith, Rachel E. Abercrombie, Graham M. Kent, Ilya Zaliapin, Rachel L. Hatch

Probabilistic seismic hazard analysis (PSHA) depends on characterizing the potential (size and location) for future damaging earthquakes and then predicting the ground motion from these earthquake sources. In order to obtain the best possible PSHA model, earthquake line sources and areal source regions must be characterized accurately. Because surface faults do not always reflect the active subsurface structures capable of producing moderate to large earthquakes (e.g., 2016 M5.8 Christchurch, NZ earthquake; 2008 M5 Mogul, NV earthquake), seismicity can be useful in characterizing subsurface seismic potential. Network improvements and increased computational techniques have facilitated a surge in advanced seismicity studies in the last decade. In western Nevada, we have leveraged abundant microseismicity and moderate seismic sequences to better characterize earthquake sources using waveform-based earthquake relocation, kinematic and stress field analysis, statistical clustering, and source parameter estimation. We present 15+ years of relocated microseismicity in the Reno-Carson-Lake Tahoe region and discuss proposed seismicity zones including seismicity rates within each, style of faulting, and seismogenic depths. We highlight discrete line sources within the diffuse seismicity zones that have consistent physical properties (e.g., style of faulting). We demonstrate a technique for identifying seismically active line sources within clustered seismicity zones using the highly-clustered Mogul earthquake swarm that occurred in urban Reno, NV in 2008. In future PHSA in Nevada, it may be increasingly important to include line sources capable of producing M5+ magnitude earthquakes identified via relocated microseismicity in place of less-detailed areal source zones.

Precise Relocations, Source Parameters, and Directivity Effect for Five Recent Earthquake Sequences Near Nevada Urban Areas

Rachel Hatch[1], Christine Ruhl[1,3], Kenneth Smith[1], Rachel Abercrombie[2]

[1] Nevada Seismological Laboratory, University of Nevada, Reno, NV 89557

[2] Department of Earth and Environment, Boston University, Boston, MA 02215

[3] UC Berkeley Seismological Laboratory, University of California, Berkeley, CA 94720

Felt earthquakes within recent sequences and swarms of seismicity in Reno, Nevada and the surrounding urban areas (2010-present) have caught attention of the public, emergency responders. Our objective is to characterize this seismicity, and its associated structures, source parameters, and hazard implications. Based on improved seismic network coverage in the Reno under additional USGS support, we develop high-resolution relocations to the Thomas Creek, NV (2015-2016; largest event = M_w 4.3), Herlong, CA (2016; largest event = M_w 4.5), Virginia City, NV (2014; largest event = M_L 3.2), Carson City, NV (2012-2015; largest event = M_L 2.9), and Truckee (2017; largest event = M_w 3.8) earthquake sequences. Relocation results for each sequence using the new GrowClust application (Trugman and Shearer, 2016), show well-defined primary fault structures with additional and more complex off-fault structures within the northern and central Walker Lane, with the majority of events occurring on unmapped faults. To assist with hazard analysis, we compile measurements of the source parameters from moment tensors, short-period mechanisms and stress drops of the larger events ($M > 2$), for each sequence. These help characterize urban seismicity and supplement results from previous studies on stress drop in the area and provide input to ground motion models. Lastly, we attempt to detect evidence for directivity, testing for unilateral and bilateral ruptures for the larger events of each sequence. Directivity effects of even moderate events near urban areas can increase risk. Preliminary results of the stress drop measurements for the sequences tested show moderate to low values for all events tested. Average values for each sequence are: Thomas Creek → 8 MPa; Herlong → 21 MPa; Carson City → 14 MPa; Virginia City → 5 MPa; Truckee → 4 MPa. Preliminary results of our directivity analysis show unilateral rupture components within the Truckee Sequence for two of the largest events in the sequence (M_w 3. 6 and M_w 3.8) as well as for several events in the 2014 Virginia City sequence. With this analysis on recent sequences, we hope to gather a better understanding of the source characteristics of sequences and identification of local seismogenic structures in order to contribute to the hazard assessment.

Fault-Scaling Relationships Depend on the Average Fault-Slip Rate

John G. Anderson, Glenn P. Biasi, and Steven G. Wesnousky

Abstract. This study addresses whether knowing the slip rate on a fault improves estimates of magnitude (Mw) of shallow continental surface-rupturing earthquakes. Based on 43 earthquakes from the database of Wells and Coppersmith (1994), Anderson et al. (1996) previously suggested that the estimates of Mw from rupture length (L_E) are improved by incorporating the slip rate of the fault (S_F). We re-evaluate this relationship with an expanded database of 80 events, which includes 56 strike-slip, 13 reverse-, and 11 normal-faulting events. When the data are subdivided by fault mechanism, magnitude predictions from rupture length are improved for strike-slip faults when slip rate is included but not for reverse or normal faults. Whether or not the slip-rate term is present, a linear model with Mw $\sim$ log L_E over all rupture lengths implies that the stress drop depends on rupture length—an observation that is not supported by teleseismic observations. We consider two other models, including one we prefer because it has constant stress drop over the entire range of L_E for any constant value of S_F and fits the data as well as the linear model. The dependence on slip rate for strike-slip faults is a persistent feature of all considered models. The observed dependence on S_F supports the conclusion that for strike-slip faults of a given length, the static stress drop, on average, tends to decrease as the fault-slip rate increases.

Characterization of Earthquake Ground Motions for Engineering Design in the Reno Basin: Geotechnical and Seismological Perspectives

Stephen Dickenson[1] and John N. Louie[2]

[1] New Albion Geotechnical, Inc., Reno, Nevada; sed@newalbiongeotechnical.com

[2] Nevada Seismological Laboratory, University of Nevada, Reno; louie@seismo.unr.edu

Current seismic codes for buildings and bridges define the earthquake ground motions used for design on the basis of regional seismic hazard assessment, bedrock characteristics, and adjustment factors for site response (i.e., Site Coefficients). The Site Coefficients have been developed from strong motion recordings supplemented with computational results from one-dimensional dynamic soil response analyses. The 1-D nature of the site response assessment precludes consideration of 2-D and 3-D effects on the characteristics of the ground motions. Therefore, the influence of basin effects is not explicitly accounted for in the code-based seismic hazard assessment. While the possible importance of basin effects on design ground motions is mentioned in the Commentary of the codes, little guidance is provided for practitioners in regions featuring geologic basins, such as Reno, Las Vegas, Los Angeles, and Seattle. We will present insights gleaned from recent civil engineering projects that have addressed basin effects on strong ground motions, and share observations made in the Reno-area basin using recorded data from earthquakes in the region, and computational models of 3D basin effects. The focus is on the seismological and engineering characterization of earthquake ground motions. The implications for engineering practice in Reno highlight the benefits of integrated project interaction by seismologists, earth scientists, and geotechnical engineers.

Comprehensive Community Velocity Models for Nevada's Urban Basins: The Key to Predicting Earthquake Ground Motions

John N. Louie[1], Michelle Dunn[1], and Aasha Pancha[2]

[1] Nevada Seismological Laboratory, University of Nevada, Reno; louie@seismo.unr.edu

[2] Aurecon Group, New Zealand

In the ten years since the USGS-sponsored Western Basin and Range Community Velocity Model (CVM) Workshop, several groups have collected comprehensive shear-velocity data in Nevada urban areas. Clark County and the City of Henderson set a new global standard for earthquake-hazard mapping by collecting the Clark County Parcel Map. The Parcel Map covers 1500 sq. km of urban and urbanizing parts of the County with over 10,000 shear-velocity measurements. Each measurement resulted in a shear-velocity profile to over 70 m depth, with a spacing of 300 m or less in the covered regions. Used by the County in permitting activities, the Parcel Map provides a detailed picture of velocity variations across an entire urban basin. The Map shows hidden alluvial fan margins, low-velocity zones along fault traces, and geostatistical metrics compatible with the fractal scales of variation common in velocity logs of wells. Together with work on deeper velocities at UNLV, and gravity analyses of basin thickness by the USGS, the Clark County Parcel Map provides a more comprehensive CVM for Las Vegas than those that exist for any other urban basin in the world.

The last ten years have also seen significant progress toward this standard in the Reno and South Lake Tahoe urban areas. UNR and Optim have completed many hundreds of measured shear-velocity profiles and several generations of gravity analyses in both areas, with USGS sponsorship. UNR students are currently documenting and publicly posting dispersion data for each measured velocity profile, and integrating different generations of gravity analyses for basin thickness. Where Reno-Tahoe leads globally is in the measurement of shear velocity below geotechnical depths, from 30 m to the basin floor at up to 1 km depth. The USGS sponsored multiple deep-basin velocity surveys by Optim across the Reno-area basin from 2012 to 2015. UNR experimented with ultra-deep velocity measurement across Reno in 2016, and achieved velocity definition to depths exceeding 2.5 km.

Community velocity models feed directly into physics-based computation of ground motions from earthquake sources that includes basin and geotechnical effects. The detailed CVMs available for Las Vegas and Reno-Tahoe have enabled comprehensive modeling of shaking across these areas from both scenario events and small recorded earthquakes over the last seven years. Sensitivity tests demonstrate that the geotechnical details in the Parcel Map, for instance, can amplify or de-amplify shaking by a factor of two. The computation of ten rupture scenarios on six faults affecting the Tahoe basin allowed creation of a new methodology, developing a simplified probabilistic hazard map for Tahoe. The new map shows that Stateline could experience "Severe" 30 cm/s levels of ground shaking at a rate exceeding once every 1400 years. This new hazard mapping methodology needs to be developed further and applied to Reno and Las Vegas.

Development of a Community Shear-Wave Velocity Profile Database in the United States

Ahdi, S.K. [1], Stewart, J.P.[1], Kwak, D.Y.[2], Yong, A.[3], Sadiq, S.[4], Ilhan, O.[5], Park, D.[4], Hashash, Y.M.A.[5], and Bozorgnia, Y.[1]

[1] Department of Civil & Environmental Engineering, UCLA (email: sahdi@g.ucla.edu)
[2] Risk Management Solutions, Inc., Newark, CA
[3] Earthquake Science Center, U.S. Geological Survey, Pasadena, CA
[4] Department of Civil and Environmental Engineering, Hanyang University, Seoul, Korea
[5] Department of Civil and Environmental Engineering, University of Illinois, Urbana-Champaign, Illinois

We describe a multi-institution effort to develop an open-access shear-wave velocity (V_S) profile database (PDB), which will include a public repository for V_S profile data in the United States. V_S profiles are an essential resource for ground motion modeling, basin velocity structure modeling, and other applications. The minimum requirements for a site to be included in the database are in situ geophysical V_S measurements and location metadata. Other information is included as available, including geotechnical logs, penetration resistance, laboratory test data, ground water elevation, and P-wave velocity profiles. The project is currently at the stage of data collection (over 4500 V_S profiles in the USA) and prototype data model development. The database will be presented as an online map-based interface with downloadable V_S profile and metadata information. While the primary focus of data collection to date has been in California, the Pacific Northwest, and central and Eastern US, it is imperative that we eventually lead a data collection effort in Nevada and the rest of the intermountain west (IMW). Access to data comprising the USGS national V_{S30} compilation has been provided; 814 locations in Nevada and the rest of the IMW are included, but the number of V_S profiles is likely lower. We seek to spread awareness about the project and solicit collaborations with V_S data owners in Nevada, with the end goal of expanding the geographic coverage of the database for future contributions to reduction of epistemic uncertainties associated with seismic site characterization and seismic hazard evaluations. Funding for this project was provided by the USGS Earthquake Hazards Program under contract number G17AP00018.

Investigating basin amplification factors for shaking in the Reno-Tahoe and Las Vegas regions for local and regional events

M. Dunn[1], J. Louie[1], K. D. Smith[1], S. Dickenson[2], R. Hatch[1]

[1] University of Nevada, Reno
[2] New Albion Geotechnical, Inc., Reno, Nevada

The impacts of seismic shaking on urban basins outside Nevada have been in the news since the 1985 Michoacán earthquake damaged Mexico City- and with another event this year. Construction projects for tall buildings in Seattle were recently delayed out of concerns that current design standards may not sufficiently account for the shaking amplification that occurs in geologic basins. Building codes in Nevada pertaining to seismic hazard use the USGS National Seismic Hazard Map Program (NSHMP), which does not include site or basin amplification factors. NGA-West2 Ground motion prediction equation (GMPE) incorporates basin amplification factors homogeneously in 1-D based on depths to certain shear-velocity values (Z1.0, Z2.5) and on the geotechnical average velocity to 30 m depth (Vs30). We investigate whether such GMPEs may adequately predict amplification in Nevada's urban basins: Reno; Tahoe; and Las Vegas. We are quantifying and comparing basin amplification factors recorded from a series of local and regional events in and around the urban areas. The focus of our analysis lies in the variation of amplification factor with spatially distributed source locations azimuthally and lithologically. Broadband records we are examining include: the 2008 Mogul sequence; 2015 M4.3 Thomas Creek; 2015 3 M ~ 5.5 Nine Mile Ranch; 1992 M 5.7 Little Skull Mountain; 2014 M4.8 Caliente; and 2014 M3.6 Enterprise events. Our initial investigation is only into peak ground velocity (PGV) ratios of basin over bedrock stations; with the intention of including other measures of shaking intensity such as spectra or duration. We have generated 3D physics-based SW4 synthetic seismograms for these events that partially account for basin effects at low frequencies of shaking (<1.0 Hz), and we can examine how well the synthetic PGV ratios predict the recorded ratios.

GPS constraints on present-day slip rates in the northernmost Walker Lane: Reno, Carson City, and Tahoe region, NV and CA

J.M. Bormann, W.C. Hammond, C. Kreemer, and G. Blewitt

We combine observations from the MAGNET GPS network in Nevada and Eastern California with data from other western U.S. continuous GPS networks to precisely measure present-day deformation in the Northern Walker Lane. We present an updated dense velocity solution (~10 km average station spacing) that spans the Sierra Nevada/Walker Lane/Basin and Range transition, and we use these velocities to infer slip rates on faults in the Reno, Carson City, Lake Tahoe, and eastern Sierra Nevada regions through an elastic block modeling approach. The velocity data show that the deformation budget in the Northern Walker Lane decreases northward from ~7 mm/yr in the central part of the region to ~5 mm/yr across the Honey Lake and Mohawk Valley faults as plate boundary deformation is increasingly accommodated on Basin and Range normal faults. Accurately representing the density of active faults in the Northern Walker Lane requires a detailed model with a relatively large number of blocks. This approach allows slip to be distributed among all likely seismic sources rather than concentrating slip on a sub-sample of major faults. A comparison of model predictions between our detailed regional model and Western U.S. scale models shows that a detailed fault representation is needed to accurately estimate fault slip rates for seismic hazard products.

Robust Estimation of Fault Slip Rates Using GPS Imaging in the Walker Lane and Western Great Basin

William C. Hammond, Corné Kreemer, Geoff Blewitt

Nevada Geodetic Laboratory, Nevada Bureau of Mines and Geology, College of Science
University of Nevada, Reno, Reno NV, 89557
whammond@unr.edu

The Walker Lane Belt is a zone of tectonic transition between the Sierra Nevada and Basin and Range in the intermountain western United States. Here, transtensional tectonic strain accumulation is released on many active strike slip and normal faults that pose a seismic hazard to nearby communities including Reno, Carson City, Mammoth Lakes, Bishop and Las Vegas. Over the past couple of decades measurements with GPS networks have improved the resolution of crustal strain rates. These measurements have transformed our understanding of the role of shear strain, block rotations, earthquake cycle transients, vertical motions, and the influence of climate conditions on active deformation. Each of these factors influence how geodetic data are compared to longer term measurements of strain release on faults, and how they can be used to improve the robustness of estimates of hazard via incorporation of the data into probabilistic seismic hazard calculations.

To integrate the data into hazard products, we use geodetic velocities to estimate the rate of slip on active faults. In the Walker Lane, estimating slip rates can be challenging for several reasons. For example, geodetically measured strain accumulation is geographically variable, and strain release is known to have occurred on hundreds of dextral, normal, and sinistral faults, folds, anticlines, and oroclinal flexures that accommodate relative motion. Also, fault slip styles can vary over short distances, even within single basins. Not all deformation occurs on large range-bounding faults, and faults can terminate without continuation into other systems. Thus, a significant fraction of the deformation budget may be “off-fault” in the sense that future strain release may not occur on previously identified faults. Moreover, measured strain accumulation is smoothed over several times the locking depths, making the estimated slip rates sensitive to foreknowledge of the location and geometry of active structures. Finally, transient deformation from the earthquake cycle, nearby magmatic systems, or climate-induced hydrological loading changes, may be present in the geodetic velocity field and potentially contaminate the measurements if not properly taken into account.

In this presentation, we will discuss recent progress in addressing these challenges, which fall into three main categories, 1) improvements in measurement of the GPS velocity field, 2) innovation in block modeling to estimate slip rates robustly, 3) better isolating the contribution of transient hydrological loading and time variable deformation from the Long Valley caldera.

Measurement of the geodetic velocity field in the Walker Lane has been refined through extending the precision and geographic coverage of GPS measurements across the western Great Basin, improved integration with regional GPS networks, and innovations in applying robust estimation techniques to the data. Through continued support from the USGS NEHRP Geodetic Networks program, regular surveys have extended the time series to a maximum of nearly ~14 years long. Long time series are absolutely essential when assessing crustal deformation rates to a precision measured in tenths of a mm/yr, and when deformation is time variable, as discussed below. The Nevada Geodetic Laboratory processes the

MAGNET data with the GIPSY/OASIS software as a part of its system that includes data from over 16,700 stations on Earth, including all of the continuously operating GPS networks in the United States. From the GPS time series, we robustly solve for station rates with the MIDAS algorithm, and use GPS Imaging to robustly estimate interpolated velocity fields, and MELD for strain rates.

Using geodetic data to estimate slip rates on faults requires knowledge of the location, strike, dip, and locking depth of the active structures, and how they connect to accommodate interseismic strain. Some of these parameters are often only roughly known. By incorporating a new strategy called “spontaneous blocks”, we are making progress in objectively and robustly modeling the slip rates, with less analyst bias, by automatically generating models from the data on fault geometries. We derive suites of solutions to quantify the uncertainty in the slip rate solutions that are attributable to the uncertainty in both the data and in prior knowledge of the geometry of fault structures and completeness of that database.

In recent years, our improved attention to the vertical rates, changes and seasonality in those rates have resulted in greater appreciation of the role of climate, drought and their effects on active crustal deformation. Uplift of the Sierra Nevada is now measured at ~1–2 mm/yr between the latitudes of Lake Tahoe and the Garlock Fault. We have now detected changes in vertical rates, including a significant increase in uplift rate during the California drought 2011–2016. This signal reveals a sensitivity of uplift to hydrological loading. We show that these changes are correlated with accelerated inflation of the magmatic system at the Long Valley caldera in eastern California, resulting in measurable changes in strain rates, magmatic uplift, and seismicity that are detectable up to 80 km from the magmatic center beneath the resurgent dome.

Robust Estimation of the Secular and Time-Variable Strain Rate Field in the American Southwest

Kreemer, C., Young, Z. Hammond, W., and Blewitt, G.

Nevada Geodetic Laboratory, NV Bureau of Mines & Geology, University of Nevada, Reno

Strain rate models derived from horizontal GPS velocities have proven to be useful for seismic hazard estimation. For example, seismic source models should ideally satisfy the implied geodetic moment rate. For this reason, the USGS seismic hazard maps have for instance added source zones to the Walker Lane to ensure that the geologic shear strain rate equals the geodetic rate. In another example, geodetic strain rate models can be used to forecast earthquake productivity when appropriate empirical scaling is applied (e.g., Bird et al., 2010, Bird and Kreemer, 2015).

Thus far, most strain rate models have lacked a robust estimation of the model uncertainties. Moreover, the Bayesian approach of the Haines and Holt type models, make the posteriori uncertainties dependent on the assumed priors. We have developed a new algorithm that provides a robust estimation of the strain rate tensor at a given location as well as the standard deviations that reflect the true scatter in the model estimate. This algorithm (called 'MELD' - Median Estimation of Local Deformation) works particularly well to retrieve the long-wavelength strain rate signal in areas of low deformation, such as intraplate North America. The performance of MELD depends on the station distribution and the amount of spatial variation in the strain rate signal. However, its robust error estimation provides a useful diagnostic to assess which strain rate features at various wavelengths should be considered significant.

We present the latest interseismic GPS velocity field compilation for the American Southwest. We then apply MELD under various assumptions on the wavelength of interest and present uncertainties maps.

Because MELD is better at pulling subtle long-wavelength signals out of noisy data, we also present two time-varying strain models. One is associated with the horizontal seasonal displacements, and another is associated with the decaying postseismic deformation after the 2010 El-Mayor Cucapah (EMC) earthquake. The seasonal model clearly identifies large-scale coherent signals, which can be divided into three domains for which the time of year of maximum deformation is different: northern and southern California, and the Great Basin. The signal is largest and most coherent in northern California, where we see compression and extension in an orientation normal to the coast and Sierra Nevada in the Spring and Fall, respectively.

Update on PBR Constraints on Ground Motion from Normal Faults

Brune, J.

Nevada Seismological Laboratory, University of Nevada, Reno, NV 89511

Dates on last rupture on the Genoa Fault and the Antelope Valley fault add to the data base for constraints on ground motion for normal faults. Also, recent acceptance of the results of foam rubber modeling of thrust faults suggests re-evaluation of the results of modeling of normal faults by both foam rubber and lattice numerical models.