Final Technical Report

External Grant Award Number:
G09AP00051

Recipient:
Board of Regents of the Nevada System of Higher Education
on Behalf of
The University of Nevada, Reno

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Title:
Gathering Critical Data Toward the Western Basin and Range CVM

NEHRP Element(s):
Element I. National and regional earthquake hazards assessments.
Element III. Research on earthquake occurrence, physics, and effects.

Keywords: Sediment thickness, Fault characterization, Basin structure and stratigraphy, Earthquake ruptures, Paleoseismology, Normal faults, Site effects, Basin effects, Seismic reflection imaging, Geophysical surveying, Seismic zonation, Engineering seismology

Research supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award number **G09AP00051**. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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NON-TECHNICAL ABSTRACT

The Reno-Carson-Tahoe urban corridor is rapidly growing in population. This population, and the economy of western Nevada, is at risk from damaging earthquakes. The University of Nevada, Reno, in partnership with the U.S. Geological Survey and Nevada technology startup Optim SDS, has committed significant resources to quantifying this risk. This partnership conducted seismic surveys, akin to those used in oil and gas exploration, along the Truckee River and in south Reno in 2009, and higher-resolution surveys in 2010. These investigations located a potentially dangerous earthquake fault running under downtown Reno, surfacing a few blocks east of Virginia St. This fault may be capable of an earthquake with a Richter magnitude of 6.0. Advanced computations indicate a wide area of Reno would shake strongly. This collaboration also calibrated a number of earthquake-recording sites in western Nevada, allowing us to better compare the computed shaking against recordings of small earthquakes. This work will provide much more accurate predictions of where the shaking will be strongest, allowing the community to target our scarce resources for disaster preparedness with more efficiency. Our objective is to protect the people and the economy of western Nevada. We also provide training in earthquake science and engineering to students at the University of Nevada.

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TECHNICAL ABSTRACT

The Truckee Meadows basin is situated adjacent to the Sierra Nevada microplate, on the western boundary of the Walker Lane. Being in the transition zone between a range-front normal fault on the west and northwest-striking right-lateral strike slip faults to the east, there is no absence of faulting in this basin. The Reno-Sparks metropolitan area is located in this basin, and with a significant population living here, it is important to know where these faults are. We undertook high-resolution seismic reflection surveys in 2009 and 2010, assisted by this project, in collaboration with a USGS group and Boise State. The surveys imaged these faults along the Truckee River, across which no faults were previously mapped in Reno, and in southern Reno near and along Manzanita Lane. The seismic images show that a simple west-dipping normal fault at the River horsetails into a swarm of short faults 4.5 km south of the River at Manzanita Lane. At the River, very high-resolution images indicate that the fault has had at least 5 meters of vertical offset in the last 11,000 years. The reflection profiles suggest additional faults not seen before. Used in conjunction with depth to bedrock calculations and gravity measurements, the seismic reflection surveys provide definitive locations of faults, as well as their orientations. Offsets on these faults indicate how active they are, and this in turn has implications for seismic hazard in the area. A physics-based shaking computation shows a peak ground velocity of almost 50 cm/sec across most of Reno, were this fault to rupture today. In addition to seismic hazard, the faults imaged here tell us something about the conduits for geothermal fluid resources in Reno.

This project also examined a low-angle normal fault south of Reno at Thomas Creek, showing that fault rupture post-dates a gravity slide, and continuing the shallow dip of the fault to more than 60 m depth.

A major portion of this funding went to calibration by shear-velocity measurement of 20 seismic-network seismometer station sites in the ANSS NN network. A shear-velocity versus depth profile to at least 30 meters depth resulted at each station. The new fault locations, along with the shear-velocity measurements, all contribute to the Nevada ShakeZoning community modeling environment and velocity model available at http://crack.seismo.unr.edu/NSZ .

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Project Period:
05/15/2009 through 11/15/2010

NEHRP Element(s):
ELEMENT I: National and regional earthquake hazards assessments.
Keywords: Sediment thickness, Fault characterization, Basin structure and stratigraphy, Earthquake ruptures, Paleoseismology, Normal faults, Site effects, Basin effects, Seismic reflection imaging, Geophysical surveying, Seismic zonation, Engineering seismology

Seismic-Reflection Surveys for Faults in the Reno-Area Basin

Part of this project was participation by UNR in a collaboration with the USGS (Stephenson/Odum group) and nees@UTexas to record seismic reflection lines in the Reno basin. As well, we collaborated with Dr. Lee Liberty of Boise State, who had FY09 USGS-ERP funding to record additional, somewhat higher-resolution reflection data in Reno. The collaborating PIs decided to begin with large-scale USGS minivibe surveys in June 2009, which were followed by UNR-Boise State surveys in March 2010 to fill in and further investigate features revealed by the June surveys. The June 2009 and March 2010 surveys were very successful, garnering much attention from regional and national news organizations.

The public page for viewing preparation and results from the Reno reflection surveys is www.seismo.unr.edu/faultsurvey. Figure 1 shows the routes of the June 2009 surveys, along the Truckee River (T1 and T2), and along Manzanita Lane 4 km south of the River (ML). The March 2010 surveys connected T1 with T2 along the Truckee River, and also detailed complex faulting geometries in the Manzanita Lane area, shown in Figure 2. When Dr. Liberty came to Reno in March 2010, we assisted him with about six UNR undergraduate students working 40 hours total each, at a pay rate of $10/hour.

Figure 3, taken from Stephenson et al. (2013), gives the results of the 2009 USGS-nees@UTexas-UNR lines T1 and T2 west-to-east along the Truckee River. This survey revealed a major fault just a half-kilometer east of the center of Reno. A west-dipping normal fault, it offsets the top of 11 million-year-old Kate Peak andesites by 500 m vertically. From these deep sections, across the 190-m "stitch" separating lines T1 from T2, Stephenson et al. (2013) observe extensional growth faulting. It is notable that downtown Reno, with high-rise hotel-casinos up to 100 m tall, is on the headwall of this fault.

Figure 4, from Frary (2012), examines the shallow geometry of this fault. The seismic section was recorded by Boise State in March 2010, with help from this project, and processed by Lee Liberty. It shows sediments ponded by the down-to-the-west fault scarp, to at least 120 m depth. The sediments are terminated by the fault in an onlap geometry. (The Truckee River flows west to east through Reno.) Even the shallowest sedimentary reflections at 10 m depth are terminated and perhaps folded by the fault. If this interface is as old as the 11 ka age of the end of the Pluvial period, then there has been at least one event since, and a total vertical offset of at least 5 meters in that period. The fault is located between 290 and 350 m northeast along the Truckee River Bike Path from Lake Street, most likely at the east abutment of the Second Street bridge across the Truckee River.

Figure 5 (from Frary, 2012; and Frary et al., 2013) integrates the new observations of this fault made during the 2009 and 2010 seismic-reflection campaigns, with the USGS Qfaults map (US Geological Survey and Nevada Bureau of Mines and Geology, 1999; dePolo, 2008). The normal fault underlying downtown Reno is noted as fault "J". Fault J has large offsets and very recent breaks at the Truckee River, and breaks up into a "horsetail" of short fault segments at Manzanita Lane, 4.5 km to the south. None of the fault segments in the horsetail has more than 100 m of total vertical offset. The horsetail is a locality with many shallow domestic geothermal wells, used for space heating. Such accommodation zones at the ends of normal faults are typical locations for geothermal resources in the Great Basin (Faulds et al., 2004).

The minivibe surveys show just one main fault at the Truckee River, and the termination of this fault into many fault segments with small offsets, 4.5 km to the south. One might argue from symmetry that this fault could extend north of the River for 4 km. South of the River the fault follows a north-striking gravity gradient (Abbott and Louie, 2000). The Bouguer anomaly gradient, down to the west by 10-20 mGal, is caused by this fault's down-to-the-west offset of the top of the 11 Ma volcanics. The gradient continues for 3 km north of the Truckee River, and the fault may well continue, too. This model could place the fault along the east side of the UNR campus.

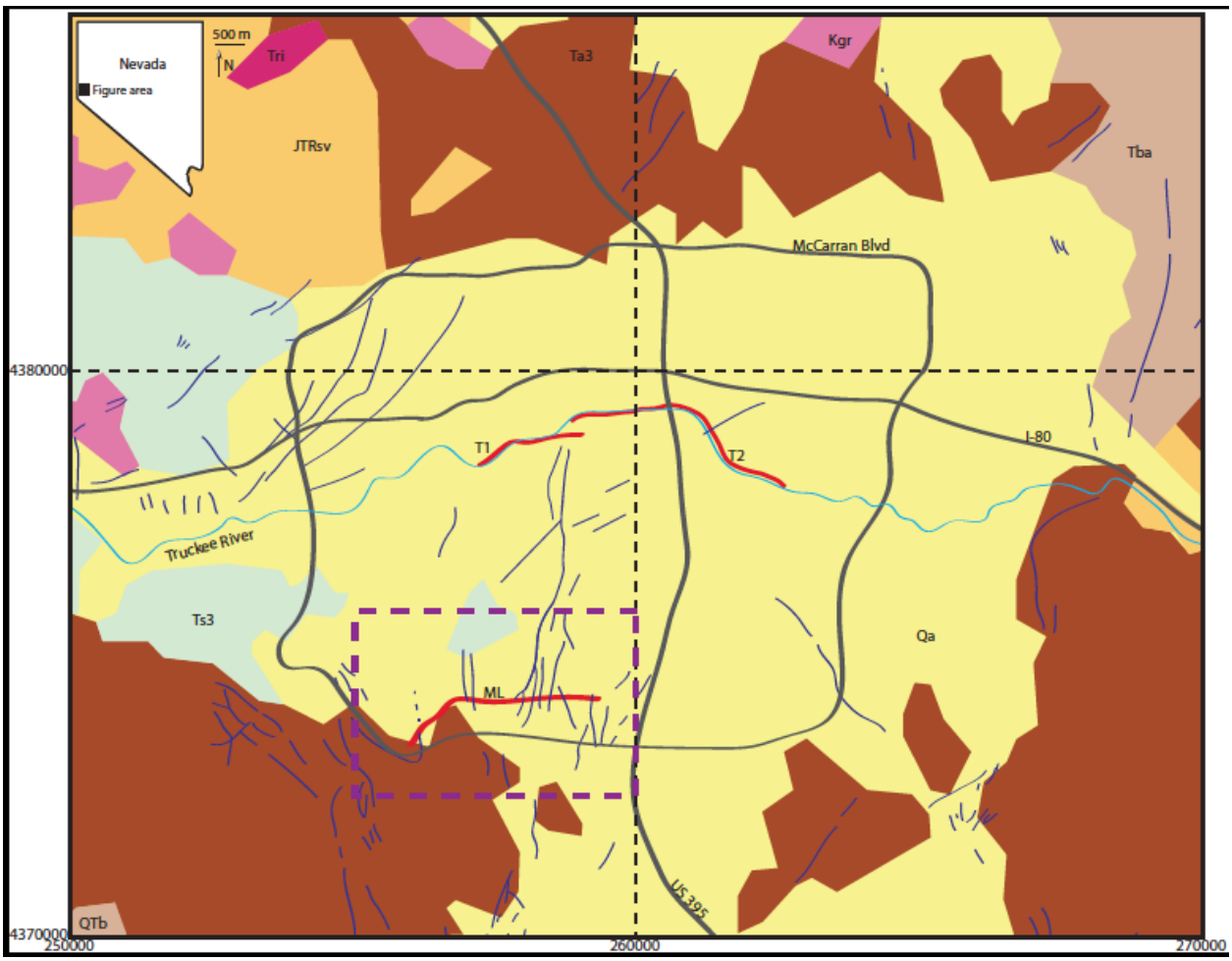

Fig. 1: Map of the Reno metropolitan area, showing generalized geology (Stewart and Carlson, 1978). Geologic units are: JTRsv- late Triassic to early Cretaceous sedimentary and volcanic deposits; Kgr- Cretaceous granitic rocks; Tri- Eocene to Miocene rhyolitic intrusive rocks; Ts3- late Eocene to late Miocene tuffaceous sedimentary rocks; Ta3- late to middle Miocene andesitic rocks; Tba- early Miocene to early Pliocene andesitic and basaltic flows; QTb- Miocene to Quaternary basalt flows; Qa- Quaternary alluvial deposits. The dark blue lines are recent faults (US Geological Survey and Nevada Bureau of Mines and Geology, 1999; dePolo, 2008) and the red lines T1, T2, and ML are the 2009 Stephenson and Odum USGS mini vibroseis seismic reflection profiles. Dashed purple box is the area of Figure 2.

Figure 6 computes a shaking map for a magnitude-6 earthquake on this normal fault, with a total rupture length of 7.5 km. Undergraduate intern Kukuk (2010) used the Nevada ShakeZoning community seismic modeling environment to model physics-based 3D wave propagation through the Reno-area basin, including all the geotechnical measurements to date in the area. The yellow areas on the right side of Figure 6 show that the peak ground velocity (PGV) reaches nearly 50 cm/s over a wide area of Reno, in this scenario.

In addition to the fault-location surveys carried out in June 2009 and March 2010, this project assisted a fault-characterization study in November 2009. A. Sarmiento and S. Wesnousky opened a trench in September 2009 across a scarp in the Mount Rose range-front fault zone that suggested low-angle normal faulting at the Sierra Front. To study this

phenomenon over a greater range of depth we completed a high-resolution seismic-reflection line 200 m long following the trench. The imaging results in figure 3 suggest an ancient landslide broken by movement on the Mt. Rose fault at low angle, from the Kell-Hills et al. (2010b) presentation at the 2010 SSA Meeting.

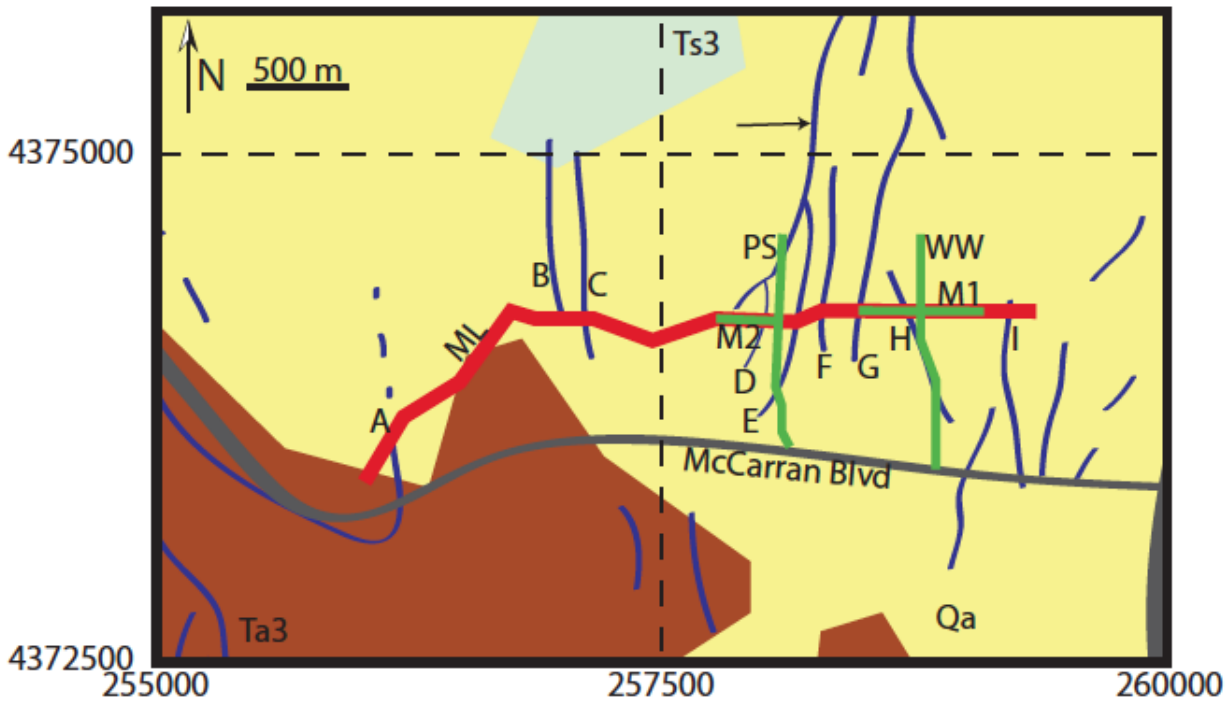

Fig. 2: Map of the Manzanita Lane area profiles. Area corresponds to purple outline in Figure 1. Geologic units are: Ts3- late Eocene to late Miocene tuffaceous sedimentary rocks; Ta3- late to middle Miocene andesitic rocks; Qa- Quaternary alluvial deposits (Stewart and Carlson, 1978). The dark blue lines are recent faults (US Geological Survey and Nevada Bureau of Mines and Geology, 1999; dePolo, 2008), red line ML is a 2009 Stephenson and Odum USGS mini vibroseis seismic reflection profile, green lines M1, M2, PS, and WW are the 2010 Boise State accelerated weight drop seismic reflection profiles. Letters A-I correspond to faults discussed in Frary et al. (2013). Arrow indicates the most prominent, continuous fault in this area.

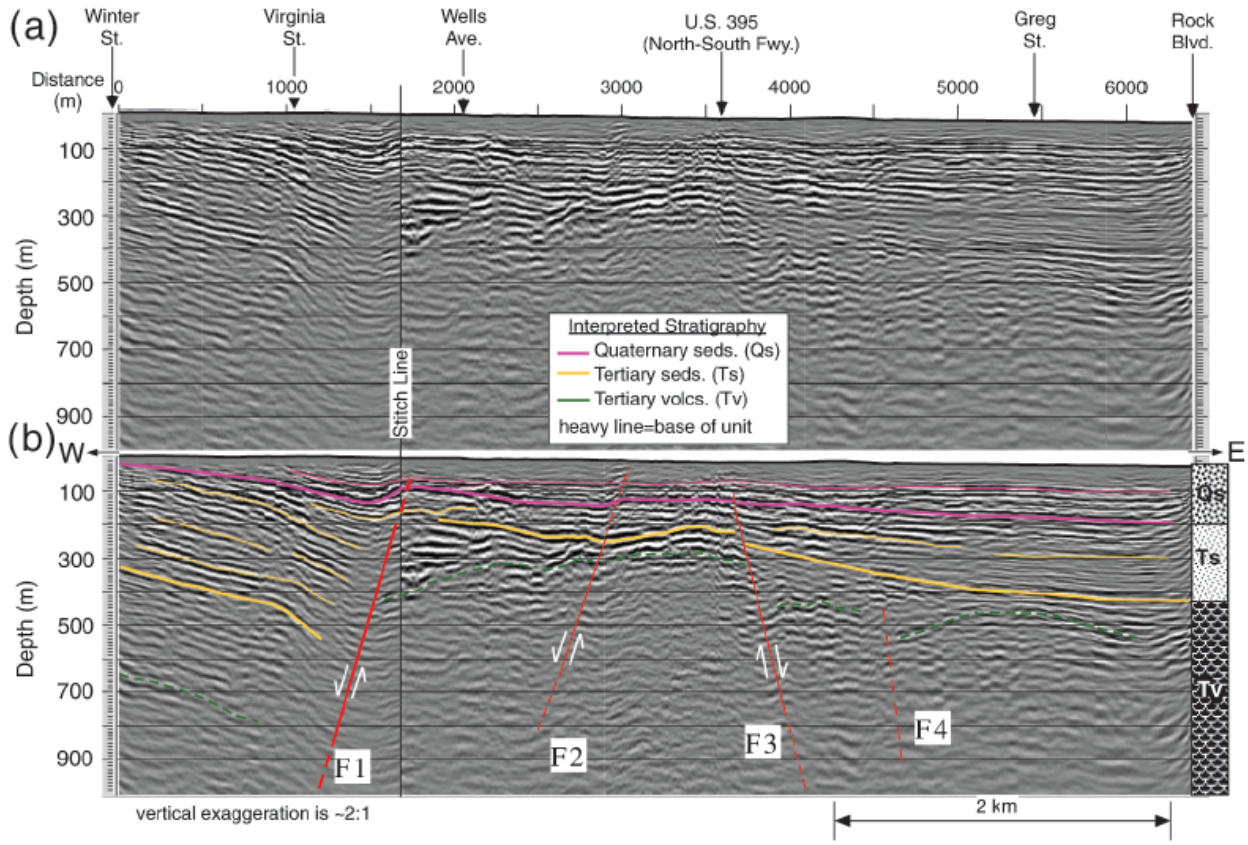

Fig. 3: P-wave Kirchhoff depth-migrated seismic image along Truckee River, T1 and T2 in Figure 1, from Stephenson et al. (2013). (a) Uninterpreted stitched section with selected road crossings shown. (b) Interpretation of a horst structure uplifting Tertiary and Quaternary basin-fill sediments bounded by normal faults beneath the central portion of the profile. The westernmost of these faults delimits the eastern edge of a sub-basin containing interpreted growth strata. Simplified stratigraphic column used for interpretation (three units are Qs, Ts, and Tv) shown to the right of the seismic section.

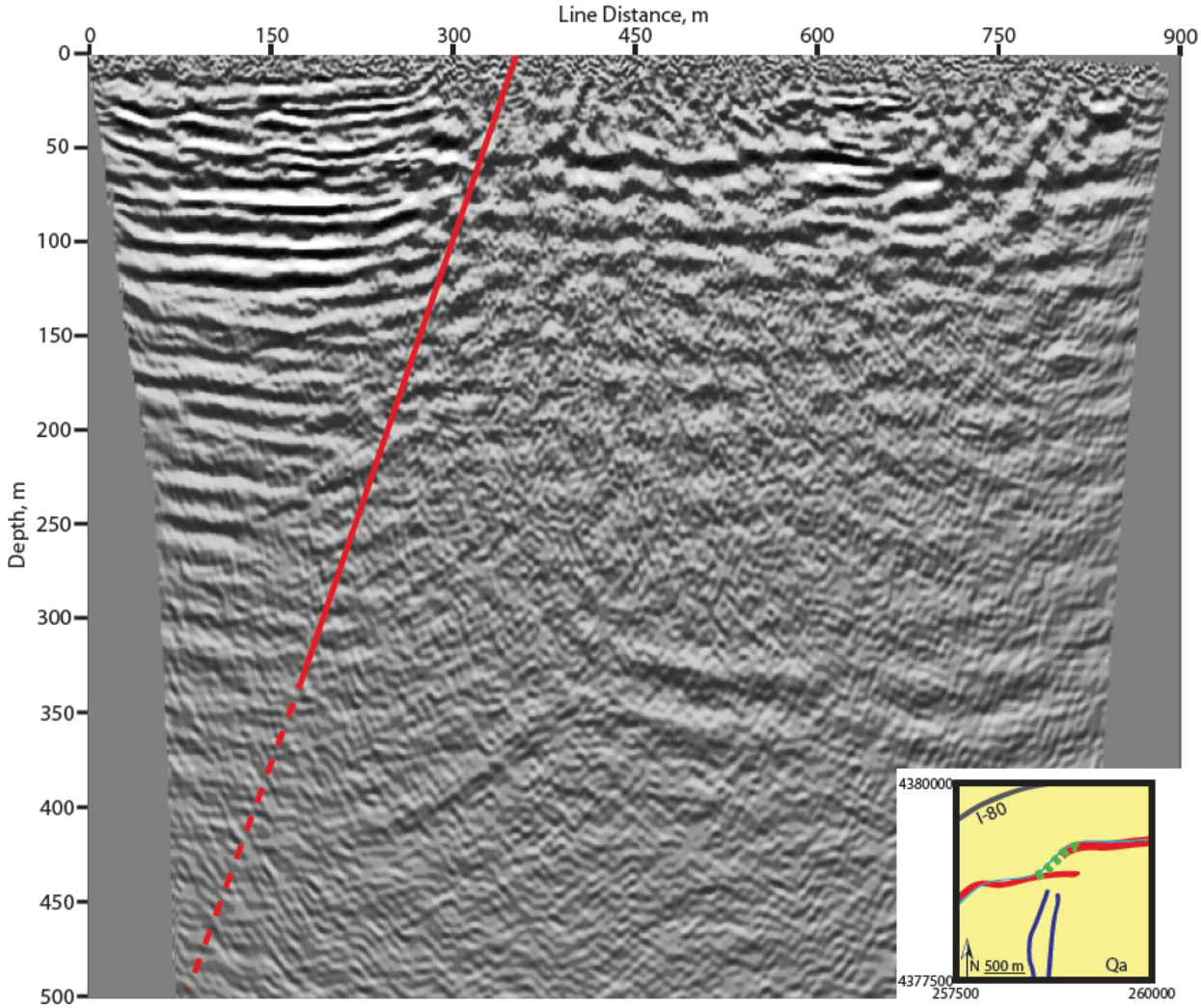

Fig. 4: Migrated depth section for the Truckee River bike path weight-drop profile. Red line shows the interpreted fault. Inset shows location of profile (green dotted line) with relation to minivib profile (red lines) and mapped faults (blue lines, US Geological Survey and Nevada Bureau of Mines and Geology, 1999; dePolo, 2008). From Frary's M.S. thesis (2012).

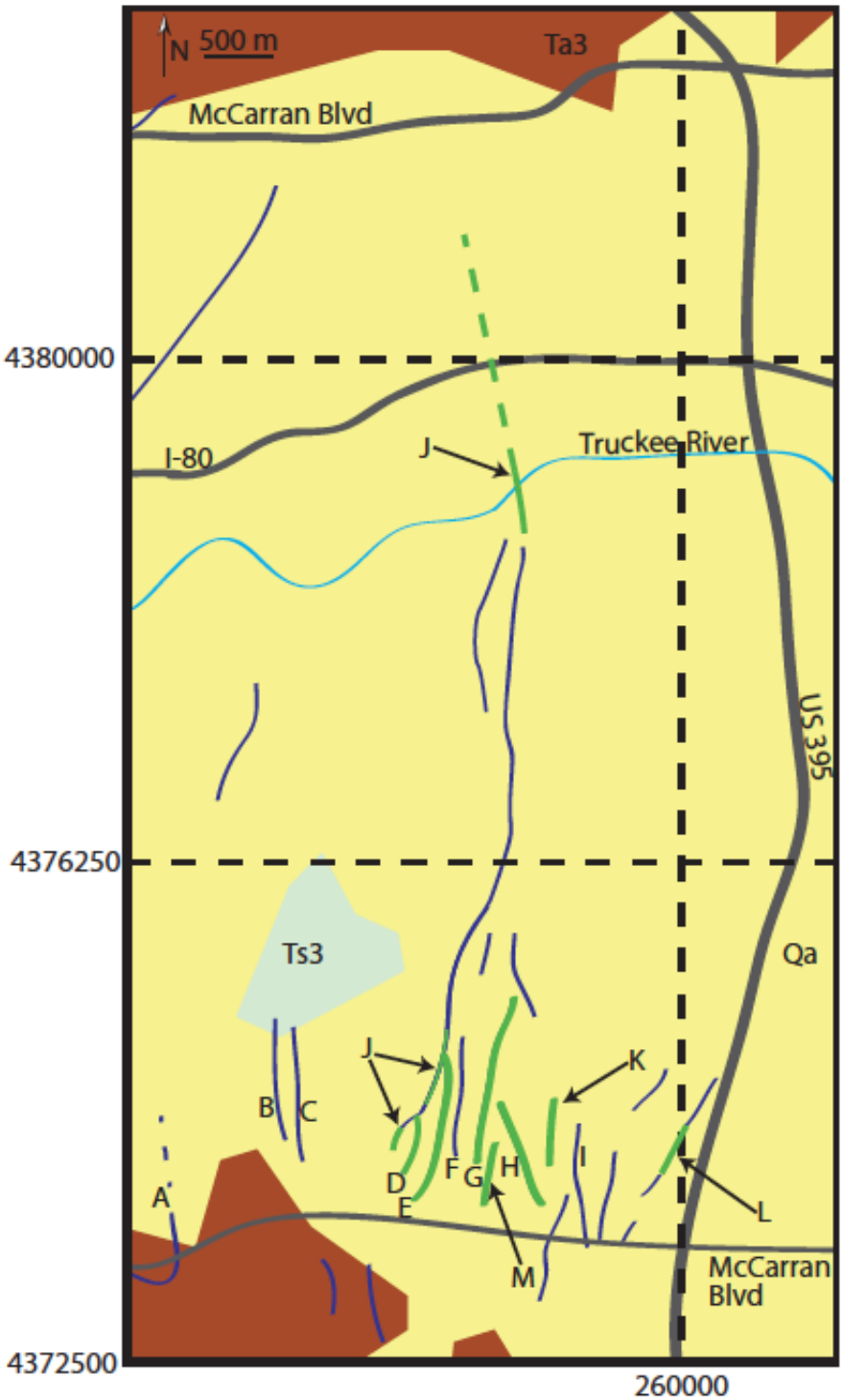

Fig. 5: Map of Reno with generalized geology. Geologic units are: Ts3- late Eocene to late Miocene tuffaceous sedimentary rocks; Ta3- late to middle Miocene andesitic rocks; Qa- Quaternary alluvial deposits (Stewart and Carlson, 1978). The dark blue lines are recent faults (US Geological Survey and Nevada Bureau of Mines and Geology, 1999; dePolo, 2008), green lines are the faults imaged in this study. Letters A-M correspond to faults discussed in Frary et al. (2013). Arrows indicate faults not previously mapped or imaged in these locations. Dashed green line is the extent of the hypothesized fault that follows the gravity anomaly.

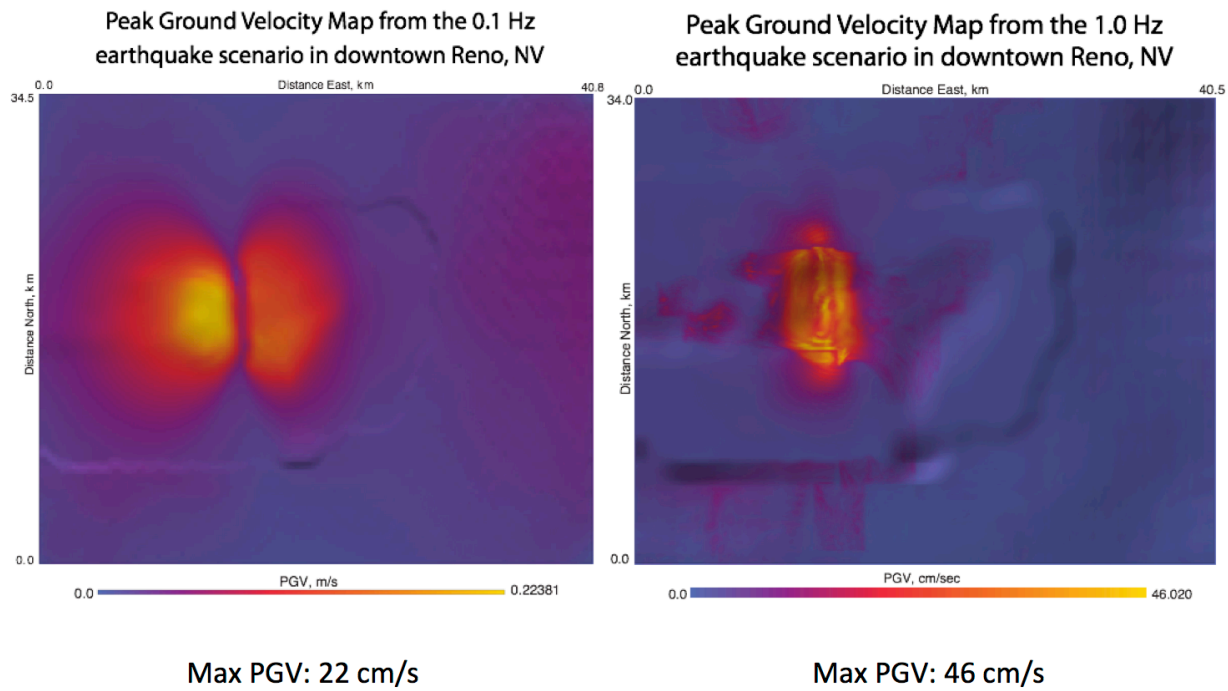

Fig. 6: Reno-area 3D, physics-based Nevada ShakeZoning peak ground velocity (PGV) shaking maps. The fault "J" identified in Figure 5 produces over 40 cm/sec shaking at 1.0 Hz, across most of the western Reno-area sub-basin. From Kukuk's Senior Project (2010).

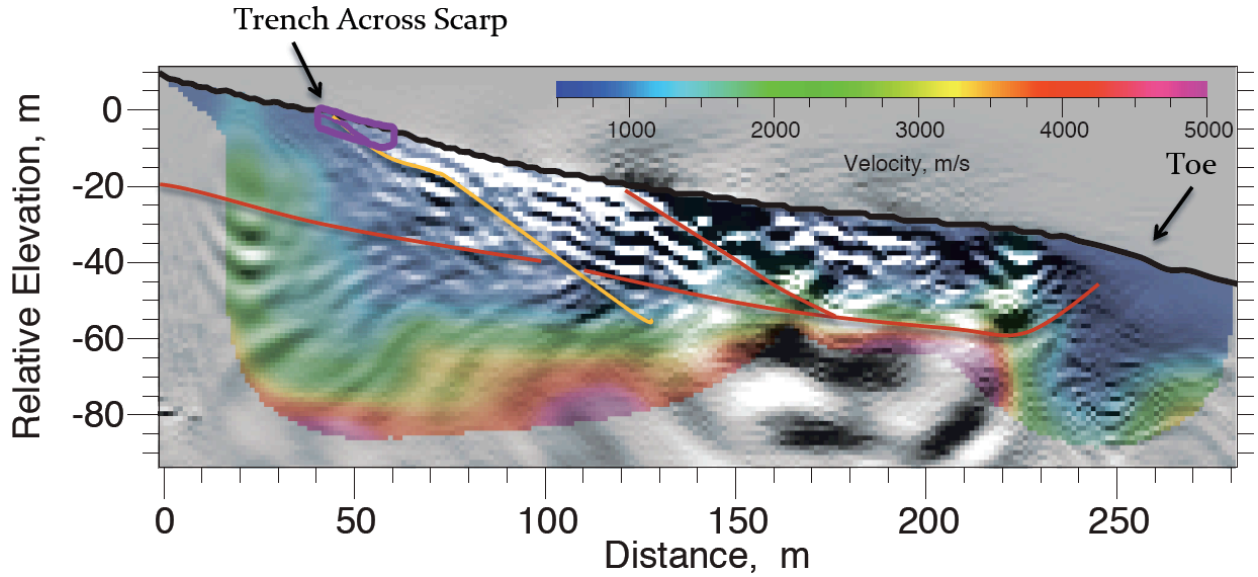

Fig. 7: Results of the November 2009 high-resolution seismic reflection experiment at the Sarmiento-Wesnousky trench across the Mt. Rose fault zone. Inverted velocities (color) were used to prestack depth migrate the reflection records. Inferred landslide slip surfaces are red; the inferred Mt. Rose fault is yellow. From Kell-Hills et al. (2010).

Refraction Microtremor Velocity Profile Results from Sites and Seismic Stations in the Reno-Carson Urban Corridor

Under a subagreement from UNR, Optim SDS measured site conditions at 20 previously unmeasured ANSS NN seismic network stations in the Reno-Carson urban corridor. Figure 8 locates these stations. Optim employed their SeisOpt® ReMi™ technology, with 12- or 24-channel linear arrays of 4.5-Hz vertical geophones 100 to 200 meters long. All arrays produced Vs30 results, vertically averaged shear-wave velocities from the surface to 30 m depth. The maximum distance of the center of any of the measurement arrays to the corresponding seismic station was 175 meters. Data were analyzed independently by experts at Optim SDS, and also by student interns at UNR under Prof. Louie's supervision. The Appendix reports the consensus results, with shear-velocity versus depth profiles, which are also available in an on-line archive at http://crack.seismo.unr.edu/vs/archive/Reno/ .

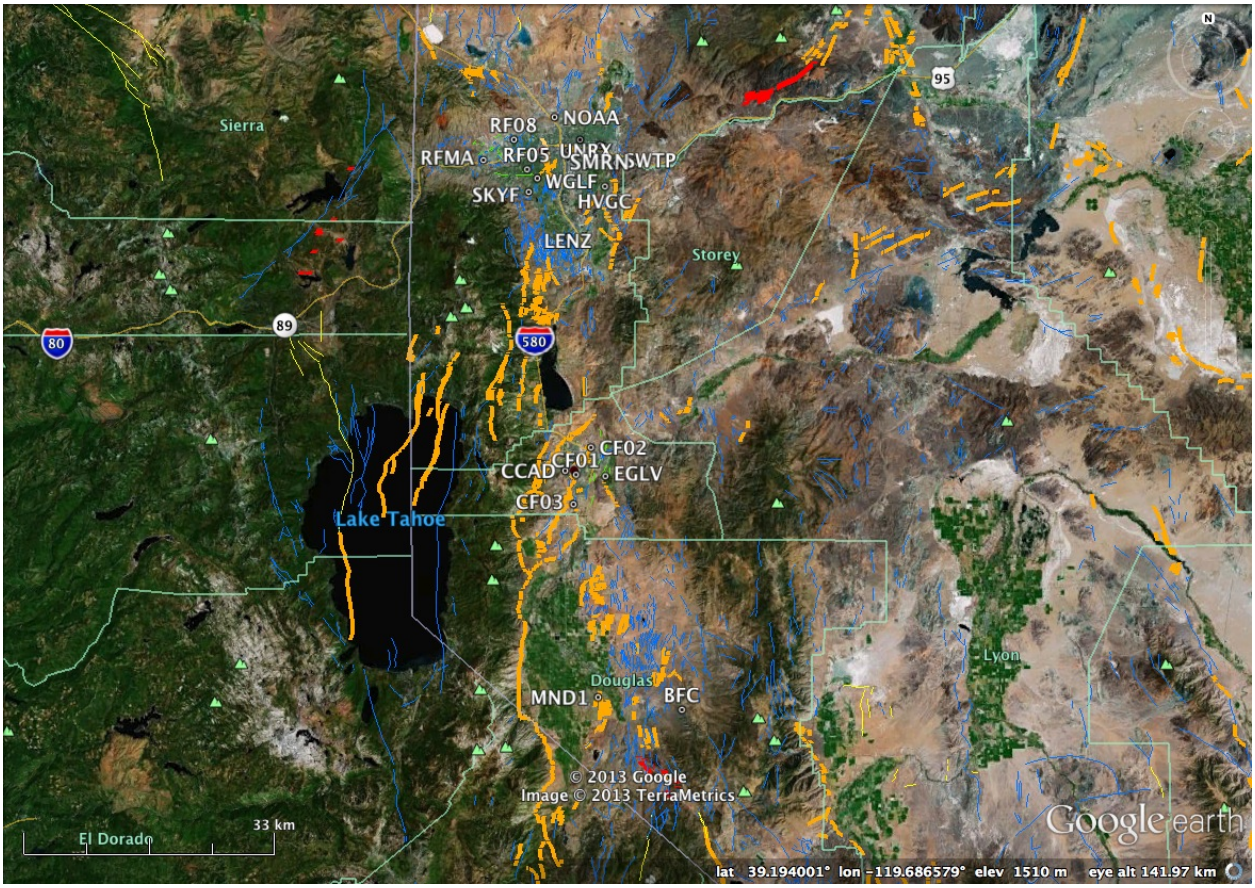

Fig. 8: Map showing names and locations of the 20 network stations characterized by this project. Also with faults from the USGS.Qfaults database (US Geological Survey and Nevada Bureau of Mines and Geology, 1999; dePolo, 2008).

It was only at station CCAD that independent analyses at Optim SDS and UNR produced any significant disagreement. SDS's model went over 2100 m/s at 111 m depth, while the student analyst at UNR did not model shear velocity above 1253 m/s. Still, Vs30 was essentially identical between the two models; 296 m/s for SDS and 288 m/s for UNR. The measurement array for CCAD may sit across the projection of a strand of the Carson City fault (US Geological

Survey and Nevada Bureau of Mines and Geology, 1999; dePolo, 2008). As well, it is in the basin but centered less than 200 m from a large outcropping of very hard Mesozoic metavolcanic rocks (Stewart and Carlson, 1978; locally known as C Hill). So high shear velocities at 100 m depth are certainly possible. We decided to adopt the student intern's simpler model for CCAD in the Appendix. For all other stations, we report Optim SDS's model.

The SKYF measurement has an unusually low Vs30 of 276 m/s. Analysts at both Optim SDS and UNR produced this result independently. The array crosses a strand of the Mt. Rose fault zone (Figure 9), so we speculate that the low velocity may be related to the Recent faulting of Quaternary gravels against Tertiary sandstone. The SKYF array could have at least half of its length on the downthrown side of the fault. Frary et al. (2013) and Frary (2012) show shallow sediments ponded west of this fault, on the Manzanita minivibe line 250 m south of the exposure. Schmauder et al. (2011) reported a Vs30 of 386 m/s from an array along the minivibe line, with more than half of its length likely to be on the up-thrown side of this fault. Another possibility is that the SKYF array may cross thick and poorly compacted artificial fill.

Fig. 9: View of an exposure of a north-striking, west-dipping strand of the Mt. Rose fault zone (USGS.Qfaults database, US Geological Survey and Nevada Bureau of Mines and Geology, 1999; dePolo, 2008), from the south. The exposure, marked with red arrows, is 176 m south of the center of the SeisOpt® ReMi™ array at the ANSS NN station SKYF.

Dissemination of Results

Project efforts contributed to the following publications and presentations made to date ("*" shows graduate and undergraduate students supported). Some of these products are primarily the results of other collaborating projects; results largely due to or supported by this grant are highlighted in brown text:

Theses:

Mahesh S. Dhar*, 2010, *Station Delays, Their Standard Deviations, and Event Relocations in the Reno-Area Basin from a Dense USArray Flexible Array Deployment During the 2008 West Reno Earthquake Swarm*: Master of Science Thesis in Geophysics, University of Nevada, Reno, defended April 5, 2010.

Janice Kukuk*, 2010, *Next-Level ShakeZoning simulations of two earthquake scenarios in downtown Reno, Nevada*: Senior Research Project, University of Nevada, Reno, completed Dec. 5.

Roxanna Frary*, 2012, *Fault Imaging with High-Resolution Seismic Reflection for Earthquake Hazard and Geothermal Resource Assessment in Reno, Nevada*: Master of Science Thesis in Geophysics, University of Nevada, Reno, defended April 13.

Peer-Reviewed Papers:

Zohar Gvirtzman and John N. Louie, 2010, 2D analysis of earthquake ground motion in Haifa Bay, Israel: *Bulletin of the Seismological Society of America*, **100**, 733-750, doi: 10.1785/0120090019.

I. M. Tibuleac, D. H. von Seggern, J. G. Anderson, and J. N. Louie, 2011, Computing Green's functions from ambient noise recorded by accelerometers and analog, broadband, and narrow-band seismometers: *Seismological Research Letters*, **82**, 661-675.

Shahar Shani-Kadmiel, Michael Tsesarsky, John N. Louie, and Zohar Gvirtzman, 2012, Simulation of seismic-wave propagation through geometrically complex basins - the Dead Sea Basin: *Bulletin of the Seismological Society of America*, **102**, 1729-1739, doi: 10.1785/0120110254.

W. J. Stephenson, R. N. Frary*, J. N. Louie, and J. K. Odum, 2013 in press, Quaternary extensional growth folding beneath Reno, Nevada, imaged by urban seismic profiling: *Bulletin of the Seismological Society of America,* **103**, no. 5 (October), doi: 10.1785/0120120311, 7 pp. Journal proof available at http://crack.seismo.unr.edu/faultsurvey/Stephenson-BSSA13.pdf

Mahesh S. Dhar*, John N. Louie, Kenneth D. Smith, Mayo Thompson*, and Annie Kell-Hills*, 2013 in revision, Station delays, their standard deviations, and event relocations in the Reno-area basin from a dense USArray Flexible Array deployment during the 2008 West Reno earthquake swarm: submitted to *Bulletin of the Seismological Society of America*, 9 March 2011, 43 pp.

Shahar Shani-Kadmiel, Michael Tsesarsky, John N. Louie, and Zohar Gvirtzman, 2013 in revision, Geometrical focusing as a mechanism for significant amplification of ground motion in sedimentary basins – analytical and numerical study: submitted to *Bulletin of Earthquake Engineering,* 30 July 2012, 20 pp.

R. N. Frary, J. N. Louie, W. J. Stephenson, J. K. Odum, S. Pullammanappallil, and L. M. Liberty, 2013 in prep., Fault imaging with high-resolution seismic reflection for earthquake hazard and geothermal resource assessment in Reno, Nevada, for Journal of Geophysical Research, 43 pp.

Presentations and Conference Papers:

I. M. Tibuleac, D. H. von Seggern, J. N. Louie and J. G. Anderson, 2009, High resolution seismic velocity structure in the Reno basin from ambient noise recorded by a variety of seismic instruments: *Geothermal Resources Council Transactions*, **33**, 143-148.

M.S. Dhar*, M. Thompson*, A. Kell-Hills*, J.N. Louie, and K.D. Smith, 2009, Station delays and their variance in the Reno-area basin from a dense deployment during the 2008 West Reno earthquake swarm: *2009 SCEC Annual Meeting* poster 1-140, Palm Springs, Calif., Sept. 13-16; abstract in *Proceedings and Abstracts*, Volume **XIX** (this abstract left out of proceedings in error). http://www.seismo.unr.edu/feature/2008/wreno/Dhar-SCEC09poster.jpg

A.M. Kell-Hills*, M.S. Dhar*, M. Thompson*, J.N. Louie, and K.D. Smith, 2009, Community-outreach efforts in data collection and analysis for the 2008 Mogul earthquake sequence: *2009 SCEC Annual Meeting* poster 1-050, Palm Springs, Calif., Sept. 13-16; abstract in *Proceedings and Abstracts*, Volume **XIX**, p. 218-219. http://www.seismo.unr.edu/feature/2008/wreno/SCEC-poster-kell.jpg

J.N. Louie, I. Tibuleac, P. Cashman, J. Trexler, W.J. Stephenson, J. Odum, S.K. Pullammanappallil, A. Pancha, and H. Magistrale, 2009, Gathering critical data toward the Western Basin and Range CVM: *2009 SCEC Annual Meeting* poster 1-011, Palm Springs, Calif., Sept. 13-16; abstract in *Proceedings and Abstracts*, Volume **XIX**, p. 195-196. http://www.seismo.unr.edu/faultsurvey/results/Louie-poster.jpg

I. M. Tibuleac, D. H. von Seggern, J. N. Louie and J. G. Anderson, 2009, High resolution seismic velocity structure in the Reno basin from ambient noise recorded by a variety of seismic instruments: presented at the *2009 Geothermal Resources Council Annual Meeting*, Reno, Nevada, Oct. 6. http://www.seismo.unr.edu/geothermal/TibuleacGRC2009_poster_noise.png

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Appendix

Fifteen Refraction Microtremor Velocity Profile Results from Sites and Seismic Stations in the Reno-Carson Urban Corridor

Following are 28 archive-format text files for our refraction microtremor measurement shear-wave velocity results from the 20 contracted ANSS NN seismic network stations, plus 8 more locations measured by UNR during earlier class projects. The additional locations are more geographically diverse, sampling the Tahoe basin, the Virginia Range, and the UNR campus. These results are also posted at http://crack.seismo.unr.edu/vs/archive/Reno/ .

```
Site name: NN Station BFC, Pine Nut Mountains, Nevada
Lat/long: 38.894103/-119.608305 WGS84
Endpoint Lat/Long: 38.894168/-119.608324 WGS84 geophone 1
Endpoint Lat/Long: 38.894344/-119.607306 WGS84 geophone 24
Seismic Station Location Lat/Long: 38.893784/-119.609404 WGS84
Array center to station distance: 99 m
Average velocity to 10 m, m/s: 349
Average velocity to 30 m, m/s: 410
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurements: ReMi
Depth of measurements: 120 m
Function stepped (y or n): yes
Posted by: John Louie (22/12/11)
Depth(m) Vs(m/s)
0 247
2.4 247
2.4 379
11.3 379
11.3 412
21.9 412
21.9 527
46.3 527
46.3 1135
105.2 1135
105.2 1404
120 1404
```

Site name: NN Station CCAD, West King St, Carson City, NV
Lat/Long: 39.164034/-119.779321 WGS84
Endpoint Lat/Long: 39.164038/-119.779891 WGS84 geophone 1
Endpoint Lat/Long: 39.164039/-119.780360 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.164092/-119.779596 WGS84
Array center to station distance: 29 m
Average velocity to 10 m, m/s: 226
Average velocity to 30 m, m/s: 288
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of Measurements: 70 m
Function stepped (y or n): yes
Posted by: John Louie (22/12/11)

Depth(m)	Vs(m/s)
0.0	226
13	226
13	367
31	367
31	1253
131	1253

Site name: NN Station CF01, South Stewart St, Carson City, NV
Lat/Long: 39.159339/-119.763111
Endpoint Lat/Long: 39.159275/-119.763108 WGS84 geophone 1
Endpoint Lat/Long: 39.160106/-119.763108 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.159295/-119.763701 WGS84
Array center to station distance: 54 m
Average velocity to 10 m, m/s: 210
Average velocity to 30 m, m/s: 287
average velocity to 100 m, m/s: 409
date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 160
Function stepped (y or n): yes
Posted by: John Louie (22/12/11)

Depth(m)	Vs(m/s)
0	138
3.7	138
3.7	302
17.7	302
17.7	379
41.9	379
41.9	539
108.9	539
108.9	662
160	662

Site name: NN Station CF02, East College Parkway, Carson City, NV
Lat/Long: 39.190404/-119.742181 WGS84
Endpoint Lat/Long: 39.190410/-119.742185 WGS84 geophone 1
Endpoint Lat/Long: 39.190522/-119.743206 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.190591/-119.741800 WGS84
Array center to station distance: 39 m
Average velocity to 10 m, m/s: 244
Average velocity to 30 m, m/s: 277
average velocity to 100 m, m/s: 900
date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 100
Function stepped (y or n): yes
Posted by: John Louie (22/12/11)

Depth(m)	Vs(m/s)
0.0	244
23.246	244
23.246	511
44.817	511
44.817	900
100.0	900

Site name: NN Station CF03, Oak Street, Carson City, NV
Lat/Long: 39.126546/-119.766946 WGS84
Endpoint Lat/Long: 39.126553/-119.766986 WGS84 geophone 1
Endpoint Lat/Long: 39.126544/-119.765927 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.125793/-119.767597 WGS84
Array center to station distance: 34 m
Average velocity to 10 m, m/s: 165
Average velocity to 30 m, m/s: 252
average velocity to 100 m, m/s: 573
date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 150
Function stepped (y or n): yes
Posted by: John Louie (22/12/11)

Depth(m)	Vs(m/s)
0	165
2.3	165
2.3	247
22.1	247
22.1	313
45.7	313
45.7	356
86.1	356
86.1	573
134.1	573
134.1	631
152.4	631

Site name: demo-UNRQuad
Lat/long: 39.538267/-119.81431821 WGS84
Endpoint Lat/Long: N/A
Endpoint Lat/Long: N/A
Seismic Station Location Lat/Long: N/A
Average velocity to 10 m, m/s: 307
Average velocity to 30 m, m/s: 398
Average velocity to 100 m, m/s: 709
Soil Classification: Not Available
Soil reference: Not Available
Geological Classification: N/A
Geological reference: N/A.
Date: 00/03/07 (dd/mm/yy)
Performed by: John Louie.
Type of measurements: ReMi
Depth of measurements: 44 m
Function stepped (y or n): yes
Posted by: Amr Wakwak (22/01/08)

Depth(m)	Vs(m/s)
0.0	307.04
13.0	307.04
13.0	513.22
31.0	513.22
31.0	601.58
44.0	601.58
44.0	1337.92
100.0	1337.92

Site name: EGGE UNR Quad
Lat/long: 39.5387103/-119.814502079 WGS84
Endpoint Lat/Long: N/A
Endpoint Lat/Long: N/A
Seismic Station Location Lat/Long: N/A
Average velocity to 10 m, m/s: 432
Average velocity to 30 m, m/s: 590
Average velocity to 100 m, m/s: 753
Soil Classification: Not Available
Soil reference: Not Available
Geological Classification: N/A
Geological reference: N/A
Date: 00/03/07 (dd/mm/yy)
Performed by: John Louie
Type of measurements: ReMi
Depth of measurements: 64.5 m
Function stepped (y or n): yes
Posted by: Amr Wakwak (22/1/08)

Depth(m)	Vs(m/s)
0.0	432.89
13.5	432.89
13.5	831.85
44.0	831.85
44.0	598.90
64.5	598.90
64.5	1166.55
100.0	1166.55

Site name: NN Station EGLV, Hidden Meadow Drive, Carson City, NV
Lat/Long: 39.159032/-119.719338 WGS84
Endpoint Lat/Long: 39.158987/-119.719331 WGS84 geophone 1
Endpoint Lat/Long: 39.159817/-119.719284 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.157900/-119.720606 WGS84
Array center to station distance: 164 m
Average velocity to 10 m, m/s: 255
Average velocity to 30 m, m/s: 303
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 80
Function stepped (y or n): yes
Posted by: John Louie (22/12/11)

Depth(m)	Vs(m/s)
0.0	255
14.5	255
14.5	367
38.5	367
38.5	1231
80	1231

Site name: UNR Campus Evans Creek Record St. Davidson Math & Science Center site, Reno, Nevada
Lat/long: 39.539145/-119.812023 WGS84
Endpoint Lat/Long: 39.539864/-119.812585 WGS84
Endpoint Lat/Long: 39.538384/-119.811587 WGS84
Seismic Station Location Lat/Long: N/A
Average velocity to 10 m, m/s: 281
Average velocity to 30 m, m/s: 364
Average velocity to 50 m, m/s: 387
Average velocity to 100 m, m/s: 488
Date: 00/04/02 (dd/mm/yy)
Performed by: J. Louie, A. Concha, W. Thelen, T. Rasmussen
Type of measurements: ReMi
Depth of measurements: 100 m
Function stepped (y or n): yes
Posted by: J. Louie (10/08/09)

Depth(m)	Vs(m/s)
0.0	208.784
4.994	208.784
4.994	427.516
64.312	427.516
64.312	841.71
164.312	841.71

Site name: NN Station HVGC, Hidden Valley Country Club, Reno, NV
Lat/Long: 39.491133/-11.720816 WGS84
Endpoint Lat/Long: 39.491129/-119.720809 WGS84 geophone 1
Endpoint Lat/Long: 39.491958/-119.720849 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.489591/-119.721196 WGS84
Array center to station distance: 175 m
Average velocity to 10 m, m/s: 265
Average velocity to 30 m, m/s: 265
Average velocity to 100 m, m/s: 406
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 150
Function stepped (y or n): yes
Posted by: John Louie (27/12/11)

Depth(m)	Vs(m/s)
0.0	148.7
2.4	148.7
2.4	214.4
7.7	214.4
7.7	307.6
35.8	307.6
35.8	565.2
105.9	565.2
105.9	581.7
141.7	581.7
141.7	921.5
150.0	921.5

Site name: NN Station LENZ, Lenz School, Reno, NV
Lat/Long: 39.426937/-119.774832 WGS84
Endpoint Lat/Long: 39.426939/-119.774849 WGS84 geophone 1
Endpoint Lat/Long: 39.426466/-119.775720 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.427133/-119.775332 WGS84
Array center to station distance: 48 m
Average velocity to 10 m, m/s: 350
Average velocity to 30 m, m/s: 365
Average velocity to 100 m, m/s: 417
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 130
Function stepped (y or n): yes
Posted by: John Louie (27/12/11)

Depth(m)	Vs(m/s)
0.0	187.0
1.7	187.0
1.7	345.9
3.7	345.9
3.7	389.8
43.3	389.8
43.3	461.1
104.4	461.1
104.4	724.2
130.0	724.2

Site name: LTAO Lake Tahoe Truckee River Outlet
Lat/long: 39.166904839/-120.14208 WGS84
Endpoint N/A
Endpoint Lat/Long: N/A
Seismic Station Location Lat/Long: N/A
Average velocity to 10 m, m/s: 194
Average velocity to 30 m, m/s: 295
Average velocity to 100 m, m/s: 366
Soil Classification: Not Available
Soil reference: Not Available
Geological Classification: N/A
Geological reference: N/A.
Date: 17/03/03 (dd/mm/yy)
Performed by: Geol 492/692 class
Type of measurements: ReMi
Depth of measurements: 65 m
Function stepped (y or n): yes
Posted by: J. Louie (10/08/09)

Depth(m)	Vs(m/s)
0.0	194.59
12.0	194.59
12.0	446.28
44.0	446.28
44.0	403.44
100.0	403.44

Site name: LTAP Lake Tahoe 40-Acre Park Tahoe City
Lat/long: 39.1647757/-120.14622443
Endpoint Lat/Long: N/A
Endpoint Lat/Long: N/A
Seismic Station Location Lat/Long: N/A
Average velocity to 10 m, m/s: 209
Average velocity to 30 m, m/s: 299
Average velocity to 100 m, m/s: 375
Soil Classification: Not Available
Soil reference: Not Available
Geological Classification: N/A
Geological reference: N/A.
Date: 17/03/03 (dd/mm/yy)
Performed by: Geol 492/692 class
Type of measurements: ReMi
Depth of measurements: 65 m
Function stepped (y or n): yes
Posted by: J. Louie (10/08/09)

Depth(m)	Vs(m/s)
0.0	207.97
11.5	207.97
11.5	408.79
44.0	408.79
44.0	427.54
100.0	427.54

Site name: LTSP Lake Tahoe Sugarpine Point State Park along Calif Hwy 89
Lat/long: 39.0565497/-120.1194965
Endpoint Lat/Long: N/A
Endpoint Lat/Long: N/A
Seismic Station Location Lat/Long: N/A
Average velocity to 10 m, m/s: 261
Average velocity to 30 m, m/s: 371
Average velocity to 100 m, m/s: 435
Soil Classification: Not Available
Soil reference: Not Available
Geological Classification: N/A
Geological reference: N/A.
Date: 17/03/03 (dd/mm/yy)
Performed by: Geol 492/692 class
Type of measurements: ReMi
Depth of measurements: 60 m
Function stepped (y or n): yes
Posted by: J. Louie (10/08/09)

Depth(m)	Vs(m/s)
0.0	261.53
11.0	261.53
11.0	360.60
43.5	360.60
43.5	582.84
100.0	582.84

Site name: NN Station MND1, Mitch Drive, Gardnerville, NV
Lat/Long: 38.906666/-119.730471 WGS84
Endpoint Lat/Long: 38.906611/-119.730447 WGS84 geophone 1
Endpoint Lat/Long: 38.905781/-119.730458 WGS84 geophone 24
Seismic Station Location Lat/Long: 38.906486/-119.731396 WGS84
Array center to station distance: 84 m
Average velocity to 10 m, m/s: 357
Average velocity to 30 m, m/s: 357
Average velocity to 100 m, m/s: 481
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 100
Function stepped (y or n): yes
Posted by: John Louie (27/12/11)

Depth(m)	Vs(m/s)
0.0	357
31.6	357
31.6	481
100.0	481

Site name: NN Station NMHS, Nevada Mental Health Services, Reno, NV
Lat/Long: 39.531664/-119.776514 WGS84
Endpoint Lat/Long: 39.531602/-119.776519 WGS84 geophone 1
Endpoint Lat/Long: 39.530774/-119.776515 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.530787/-119.776396 WGS84
Array center to station distance: 97 m
Average velocity to 10 m, m/s: 500
Average velocity to 30 m, m/s: 370
Average velocity to 100 m, m/s: 399
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 120
Function stepped (y or n): yes
Posted by: John Louie (27/12/11)

Depth(m)	Vs(m/s)
0.0	168
1.9	168
1.9	243
3.2	243
3.2	361
6.7	361
6.7	508
18.1	508
18.1	369
72.8	369
72.8	508
109.5	508
109.5	906
120.0	906

Site name: NN Station NOAA, Truckee Meadows Community College, Reno, NV
Lat/Long: 39.568193/-119.796267 WGS84
Endpoint Lat/Long: 39.568200/-119.796290 WGS84 geophone 1
Endpoint Lat/Long: 39.568183/-119.797357 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.568085/-119.795813 WGS84
Array center to station distance: 42 m
Average velocity to 10 m, m/s: 342
Average velocity to 30 m, m/s: 402
Average velocity to 100m, m/s:
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 150
Function stepped (y or n): yes
Posted by: John Louie (03/01/12)

Depth(m)	Vs(m/s)
0.0	219
3.2	219
3.2	342
6.7	342
6.7	427
18.1	427
18.1	512
38.4	512
38.4	727
101.0	727
101.0	2033
137.5	2033
137.5	3305
150.0	3305

Site name: NN Station PICO, Marvin Piccolo School, Reno, NV
Lat/Long: 39.431181/-119.774952 WGS84
Endpoint Lat/Long: 39.430987/-119.775421 WGS84 geophone 1
Endpoint Lat/Long: 39.431377/-119.774518 WGS84 geophone 12
Seismic Station Location Lat/Long: 39.431302/-119.775505 WGS84
Array center to station distance: 39 m
Average velocity to 10 m, m/s: 300
Average velocity to 30 m, m/s: 344
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 80
Function stepped (y or n): yes
Posted by: John Louie (27/12/11)

Depth(m)	Vs(m/s)
0.0	255
4.6	255
4.6	367
51.1	367
51.1	608
80.0	608

Site name: NN Station RF05, Hunter Lake Drive, Reno, NV
Lat/Long: 39.508924/-119.835883 WGS84
Endpoint Lat/Long: 39.508849/-119.835890 WGS84 geophone 1
Endpoint Lat/Long: 39.508019/-119.835884 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.508889/-119.836957 WGS84
Array center to station distance: 61 m
Average velocity to 10 m, m/s: 427
Average velocity to 30 m, m/s: 464
Average velocity to 100 m, m/s: 580
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 120
Function stepped (y or n): yes
Posted by: John Louie (29/12/11)

Depth(m)	Vs(m/s)
0.0	427
24.3	427
24.3	742
83.3	742
83.3	749
120.0	749

Site name: NN Station RF08, North McCarran Boulevard, Reno, NV
Lat/Long: 39.543528/-119.855675 WGS84
Endpoint Lat/Long: 39.543517/-119.855755 WGS84 geophone 1
Endpoint Lat/Long: 39.543113/-119.856687 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.546692/-119.856094 WGS84
Array center to station distance: 100 m
Average velocity to 10 m, m/s: 518
Average velocity to 30 m, m/s: 489
Average velocity to 100 m, m/s: 519
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 100
Function stepped (y or n): yes
Posted by: John Louie (29/12/11)

Depth(m)	Vs(m/s)
0.0	519
14.9	519
14.9	462
55.5	462
55.5	541
100.0	541

Site name: NN Station SKYF, Skyline Boulevard, Reno, NV
Lat/Long: 39.482092/-119.835512 WGS84
Endpoint Lat/Long: 39.482047/-119.835547 WGS84 geophone 1
Endpoint Lat/Long: 39.482687/-119.834870 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.482488/-119.834002 WGS84
Array center to station distance: 137 m
Average velocity to 10 m, m/s: 276
Average velocity to 30 m, m/s: 276
Average velocity to 100 m, m/s: 394
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 120
Function stepped (y or n): yes
Posted by: John Louie (03/01/12)

Depth(m)	Vs(m/s)
0.0	369
4.3	369
4.3	261
28.3	261
28.3	314
42.7	314
42.7	549
107.9	549
107.9	1007
121.9	1007

Site name: NN Station SMRN, East Lincoln Way, Sparks, NV
Lat/Long: 39.537051/-119.728365 WGS84
Endpoint Lat/Long: 39.537052/-119.728338 WGS84 geophone 1
Endpoint Lat/Long: 39.537073/-119.727263 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.526992/-119.728297 WGS84
Array center to station distance: 7 m
Average velocity to 10 m, m/s: 259
Average velocity to 30 m, m/s: 286
Average velocity to 100 m, m/s: 331
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 130
Function stepped (y or n): yes
Posted by: John Louie (29/12/11)

Depth(m)	Vs(m/s)
0.0	259
13.2	259
13.2	312
75.6	312
75.6	520
130.0	520

Site name: NN Station SPHI, 12th Street, Sparks, NV
Lat/Long: 39.543705/-119.759228 WGS84
Endpoint Lat/Long: 39.543708/-119.759240 WGS84 geophone 1
Endpoint Lat/Long: 39.543520/-119.758119 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.543489/-119.758299 WGS84
Array center to station distance: 84 m
Average velocity to 10 m, m/s: 257
Average velocity to 30 m, m/s: 312
Average velocity to 100 m, m/s: 376
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 130
Function stepped (y or n): yes
Posted by: John Louie (29/12/11)

Depth(m)	Vs(m/s)
0.0	116
1.5	116
1.5	247
3.3	247
3.3	352
76.2	352
76.2	532
128.0	532
128.0	647
130.0	647

Site name: NN Station SWTP, Truckee Meadows Water Reclamation, Reno, NV
Lat/Long: 39.515743/-119.703698 WGS84
Endpoint Lat/Long: 39.516234/-119.704395 WGS84 geophone 1
Endpoint Lat/Long: 39.515187/-119.702737 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.516194/-119.704404 WGS84
Array center to station distance: 78 m
Average velocity to 10 m, m/s: 346
Average velocity to 30 m, m/s: 557
Average velocity to 100 m, m/s: 914
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 170
Function stepped (y or n): yes
Posted by: John Louie (03/01/12)

Depth(m)	Vs(m/s)
0	165
2.5	165
2.5	258
7.4	258
7.4	1119
15.9	1119
15.9	1119
51.2	1119
51.2	1354
163.0	1354
163.0	2500
170.0	2500

Site name: NN Station UNRX, Mill Street, Reno, NV
Lat/Long: 39.513068/-119.748319 WGS84
Endpoint Lat/Long: 39.513068/-119.748294 WGS84 geophone 1
Endpoint Lat/Long: 39.513434/-119.749530 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.513987/-119.749296 WGS84
Array center to station distance: 137 m
Average velocity to 10 m, m/s: 334
Average velocity to 30 m, m/s: 335
Average velocity to 100 m, m/s: 371
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 150
Function stepped (y or n): yes
Posted by: John Louie (29/12/11)

Depth(m)	Vs(m/s)
0.0	335
30.6	335
30.6	374
62.4	374
62.4	642
150.0	642

Site name: VRRT 5-12 near N Virginia Ra fault
Lat/long: 39.4758655/-119.67171589 WGS84
Endpoint Lat/Long: N/A
Endpoint Lat/Long: N/A
Seismic Station Location Lat/Long: N/A
Average velocity to 10 m, m/s: 486
Average velocity to 30 m, m/s: 623
Average velocity to 100 m, m/s: 850
Soil Classification: Not Available
Soil reference: Not Available
Geological Classification: N/A
Geological reference: N/A
Date: 15/03/03 (dd/mm/yy)
Performed by: Geol 492/692 class
Type of measurements: ReMi
Depth of measurements: 50 m
Function stepped (y or n): yes
Posted by: J. Louie (10/08/09)

Depth(m)	Vs(m/s)
0.0	486.44
10.5	486.44
10.5	663.16
25.0	663.16
25.0	1013.93
100.0	1013.93

Site name: VRRT 13-32
Lat/long: 39.47593901/-119.6770075 WGS84
Endpoint Lat/Long: N/A
Endpoint Lat/Long: N/A
Seismic Station Location Lat/Long: N/A
Average velocity to 10 m, m/s: 404
Average velocity to 30 m, m/s: 555
Average velocity to 100 m, m/s: 683
Soil Classification: Not Available
Soil reference: Not Available
Geological Classification: N/A
Geological reference: N/A
Date: 16/03/03 (dd/mm/yy)
Performed by: Geol 492/692 class
Type of measurements: ReMi
Depth of measurements: 50 m
Function stepped (y or n): yes
Posted by: J. Louie (10/08/09)

Depth(m)	Vs(m/s)
0.0	398.08
9.0	398.08
9.0	639.07
25.0	639.07
25.0	762.24
100.0	762.24

Site name: NN Station WGLF, Foley Way, Reno, NV
Lat/Long: 39.499329/-119.821317 WGS84
Endpoint Lat/Long: 39.498469/-119.821693 WGS84 geophone 1
Endpoint Lat/Long: 39.500036/-119.820968 WGS84 geophone 24
Seismic Station Location Lat/Long: 39.498496/-119.821503 WGS84
Array center to station distance: 92 m
Average velocity to 10 m, m/s: 324
Average velocity to 30 m, m/s: 365
Average velocity to 100 m, m/s: 410
Date: 16/11/10 (dd/mm/yy)
Performed by: Optim SDS
Type of measurement: ReMi
Depth of measurements: 120
Function stepped (y or n): yes
Posted by: John Louie (29/12/11)

Depth(m)	Vs(m/s)
0.0	182
2.4	182
2.4	297
7.3	297
7.3	428
21.0	428
21.0	434
108.9	434
108.9	746
120.0	746