Seismic reflection imaging of the Mount Rose fault zone, Reno, Nevada

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Abstract

Five new high-resolution seismic reflection profiles acquired through the Reno metropolitan area identify faults along the Mount Rose fault system. This 38 km long, ~3 km wide fault zone accommodates upwards of 5 mm/yr vertical slip, extends through the Reno/Carson City metropolitan area, and is characterized as one of the greatest earthquake hazards for Nevada. New seismic profiles identify faults that cut very near-surface sediments and correspond with changes in surface topography. A seismic profile along the Truckee River suggest the Mount Rose fault system extends farther north than previously identified, and likely crosses the downtown Reno corridor. Lateral variations and offsets in late Quaternary stratigraphy in South Reno identified on four seismic profiles suggest numerous active faults may control the evolution of the southern portions of the Reno basin. These new data can pinpoint trench locations for paleoseismic studies to better constrain slip rates and contribute to probabilistic hazard maps for the region.

Introduction

Nevada is the 3rd most seismically active state in the United States with more than 60 earthquakes of magnitudes 5.5 and above in the past 150 years (Nevada Seismological Laboratory). The Reno/Carson City, Nevada metropolitan area, with a population of 340,000 (2000 census), has had 13 M6 and above earthquakes during that same period (Figure 1; dePollo et al., 1997), yet faults and fault systems in the area are poorly understood. With the frequency of regional M6 events in the upper 10 km and the presence of mapped and likely active normal faults in the Reno metropolitan area that are capable of supporting a M7 earthquake (e.g., dePollo et al., 1997), earthquake hazard assessments of faults in the Reno area must be further advanced.

Reno is located along the western margin of the Basin and Range province and within the Walker Lane shear zone (e.g., Stewart, 1988). Active extension and dextral shear over the past 12 to 3 Ma years has controlled the regional tectonic landscape that includes the Reno Basin (Trexler et al., 2000). The area is extending westward approximately 10-12 mm/yr (Thatcher et al., 1999) and the right lateral Walker Lane shear zone, sub-parallel to the San Andreas fault system, accommodates up to 25% of the relative Pacific–North American plate boundary motion (e.g., Dokka and Travis, 1990; Dixon et al., 2000).

The Reno Basin is a fault-bounded graben, with range front fault zones along the Carson Range to the west and the Virginia Range to the east. Numerous faults also exist within the Reno Basin, including the northern extension of the Mount Rose fault system that likely controls the segmentation of the ~1 km deep Reno Basin (Abbot and Louie, 2000). Multiphase faulting in this area may imply a change in stress regimes over the past few million years, thus potentially changing the current hazards associated with mapped faults. Ramelli and dePolo (1997) estimate a late Holocene slip rate between 1.1-3.8 mm/yr along the southern portions of the fault system and Sawyer (1999) categorizes vertical slip on this fault as upwards of 5 mm/yr. The fault zone is mapped as a highly distributed network of echelon and anastomosing north- and northwest-striking faults from the Carson Range north into Reno. The northern portion of this fault system, in the downtown Reno area, is poorly understood (Figure 1).

The estimated 38 km long Mount Rose fault zone with documented latest Quaternary motion, strikes N5E, extends from the east flank of the northern Carson Range into the Reno metropolitan area (Sawyer, 1999). The Reno Basin extends north of Interstate 80, yet mapped faults associated with basin formation terminate farther south (e.g., Abbot and Louie; Ramelli and dePolo, 1997, Sawyer, 1999). Assuming the complete 38 km length of the fault were to rupture during an earthquake, empirical measurements suggests a M6.7 earthquake would result (Wells and Coppersmith, 1994). With estimated vertical slip rates defined by Ramelli and dePolo (1997) and maximum surface displacement of ~1 m for a M6.7 event (Wells and Coppersmith, 1994), recurrence intervals may be as little as every few hundred years to accommodate measured slip rates. Here, I describe results from a seismic survey to examine fault connectivity, slip distribution among fault strands, and length of the Mount Rose fault system to better constrain the hazard for the Reno metropolitan area. I utilize the seismic character in the upper few hundred meters depth and nearby water well logs to interpret each seismic profile. Although shallow bedrock depths and low deposition rates of late Quaternary alluvial deposits make slip rate estimates difficult with seismic images alone, these data provide key locations to conduct paleoseismic studies to estimate slip rates and hazards associated with the identified faults along the Mount Rose fault system.

Seismic Reflection Studies

Downtown Reno

Truckee River seismic profile

The 0.9 km Truckee River seismic profile was acquired along the south shore Truckee River bike path west from Lake Street east across North Wells Avenue, downtown Reno (Figure 1). This profile was acquired to identify faulting related to the Mount Rose fault system beyond previously identified fault strands and to complement a nearby USGS vibroseis seismic profile that could not operate along the bike path beneath the 2nd Street overpass (Figure 2; Frary et al., 2009). An elevation change of less than 5 m across the profile is observed while the profile crossed beneath East 2nd Avenue at position 2100 and Wells Avenue at station 2250 (Figure 3). Station 2000 is located along the east shoulder of Lake Avenue. Data were acquired at a 3 m shot and receiver spacing using a hitch-mounted 80 kg accelerated weight drop source (Figure 2). Ten Hz geophones were placed along the north shoulder of the bike path (south river shoulder) and data were recorded with a 120-channel seismic system to maintain 60-fold coverage along the profile. The bike path provided a corridor free of vehicle noise along the profile; however foot traffic and overpass vehicle traffic was continuous during the time of acquisition. Signal penetration and data quality were, in part, controlled by near-surface conditions that included coarse-grained sediments and boulders deposited along the Truckee River.

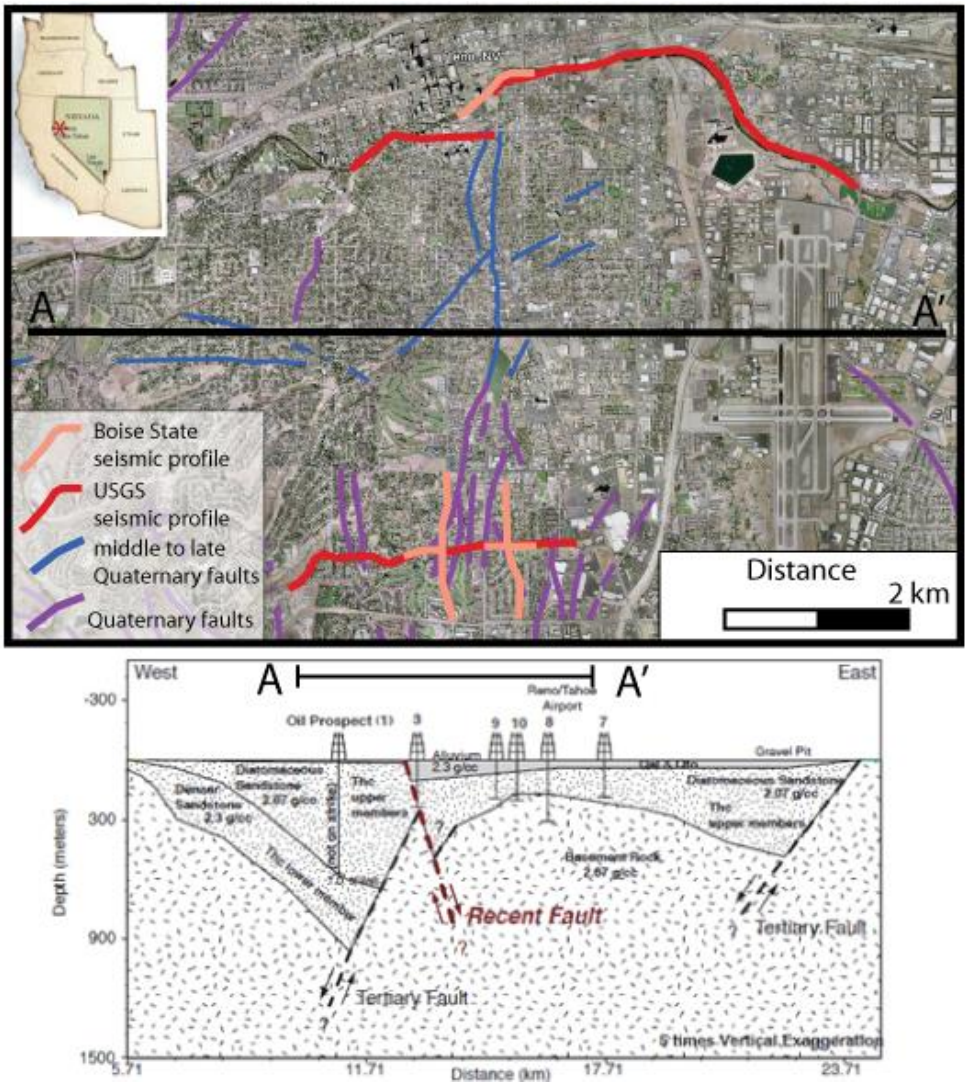

Figure 1. a) Aerial photo of the Reno downtown area with mapped faults from the USGS database (Sawyer, 1999). Blue lines represent faults with confirmed middle to late Quaternary motion. Purple lines represent faults with confirmed Quaternary motion. Red lines represent 2009 USGS seismic profiles and tan lines represent Boise State seismic profiles. b) Geologic cross section across the Reno Basin (from Abbot and Louie, 2000) showing Tertiary faults cut by a Recent fault. This recent fault likely represents the Mount Rose fault zone.

Reflections appear to more than 0.2 s two-way travel time or approximately 200 m depth along the length of the profile (Figure 3). The western portions of the Truckee River seismic profile suggest flat-lying strata are present in the upper few hundred meters depth. The consistent set of reflectors to >200 m depth suggest fine-grained deposits dominate the subsurface west of position 2100. East of position 2100, fewer reflectors in the upper 200 m appear on the stack with a lower apparent frequency and greater topography on each horizon. I interpret a high-angle normal fault at position 2100 that is located along strike of the Mount Rose fault system (Figure 1). The seismic character across this fault suggests undeformed finer-grained (late Quaternary?) deposits to the west may juxtapose more coarse-grained alluvium to the east and extends within the upper few meters of the surface. Although the bedrock reflector was not imaged and no age control is available to determine slip rates, the proximity of this fault to downtown Reno and offsets that appear to shallow depths suggests trench studies should follow this investigation to assess the earthquake risk to downtown Reno.

Figure 2. (left) Boise State seismic source truck beneath the East 2nd Street bridge along the Truckee River seismic profile. (right) University of Nevada Reno student Brady Flinchum operating the controls of the hitch-mounted Boise State seismic source along the Warren Way seismic profile.

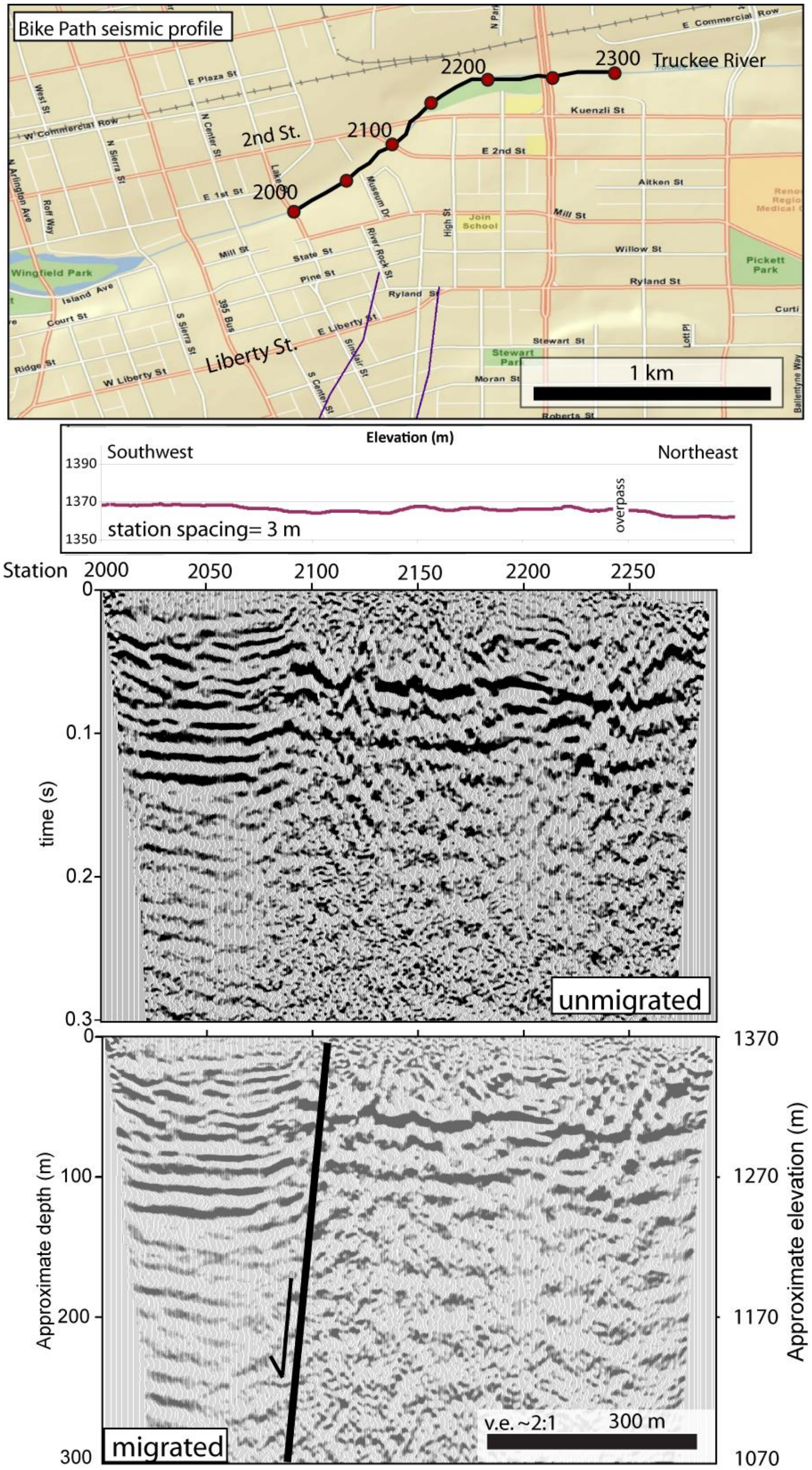

Figure 3. Truckee River seismic profile station location map, elevation profile, unmigrated traveltime image, and migrated, depth converted and interpreted seismic image. Note the change in reflection character at position 2100. Purple lines along the southern portions of the map represent faults with confirmed middle to late Quaternary motion (Sawyer, 1999).

South Reno

Manzanita seismic profile

Seismic imaging along Manzanita Lane was acquired on two profiles. One 0.25 km long seismic profile was acquired west from Plumas Street to image the upper 100 m across a previously identified fault (Figures 1 and 4; Frary et al., 2009). The second 0.45 km long profile was acquired east from Lakeside Lane to image additional faults associated with the Mount Rose fault system (Sawyer, 1999). Each profile was acquired with 2 m receiver and 1 m source spacing with an 80 kg hitch-mounted accelerated weight drop source, 10 Hz geophones, and a 120-channel seismograph. Three nearby water wells place bedrock at less than 60 m depth along the western profile and ~110 m depth along the eastern profile (Figure 4). Manzanita Lane is the location of a USGS vibroseis seismic profile acquired in 2009 (Frary et al., 2009).

The Manzanita seismic profiles image to Tertiary bedrock depths (Figure 4; yellow circles). Offsets in near-surface (late Quaterary?) reflectors suggest faults may cut to within a few meters of the surface. I interpret one fault at position 5120, west of Plumas Street that correlates with a slope break along the road surface and offsets the interpreted bedrock reflector. Additional reflector offsets east of Lakeside Lane may also represent late Quaternary faulting. Due to the near-surface expression of these interpreted faults, paleoseismic trenches may best quantify the history of these faults.

Plumas seismic profile

The 1.5 km long Plumas seismic profile was acquired from South McCarren Blvd north to Moana Lane (Figure 5). This profile crosses two faults associated with the Mount Rose fault system and crosses the Manzanita Lane Boise State and USGS seismic profiles (Sawyer, 1999, Frary et al., 2009; Figure 1). Elevations increase to the south approximately 20 m along the length of the profile with a sharp elevation break at position 920. The profile was acquired with 3 m source and receiver spacing using an 80 kg hitch-mounted accelerated weight drop source, 10 Hz geophones, and a 120-channel seismograph. Four nearby water wells place bedrock at less than 100 m depth south of position 1050 and below water well depths to the north (Figure 5). A gap in data acquisition was necessary across Manzanita Lane (position 1000).

Signal penetration varied considerably along the Plumas seismic profile. Along the southern portions of the profile, a single reflector appears at depths less than 100 m that correlates with nearby water well data as a shallow Tertiary bedrock reflector (yellow circles). To the north, reflectors appear to more than 300 m depth, consistent with sediments occupying a sedimentary basin. Discontinuities in the bedrock reflector suggest numerous faults may surface along Plumas Street. At positions 820 and 930, offset in the shallow bedrock reflector may imply late Quaternary faulting. Given the Tertiary bedrock age, these faults are not necessarily active; however, a break in surface elevation at position 920 suggests at least one fault may have recent motion. Farther north, I interpret two faults near position 1100 that control the south basin margin identified by Abbott and Louie (2000). These faults offset late Quaternary(?) strata, correlate with surface topography (scarp?) and warrant further investigation to determine slip history.

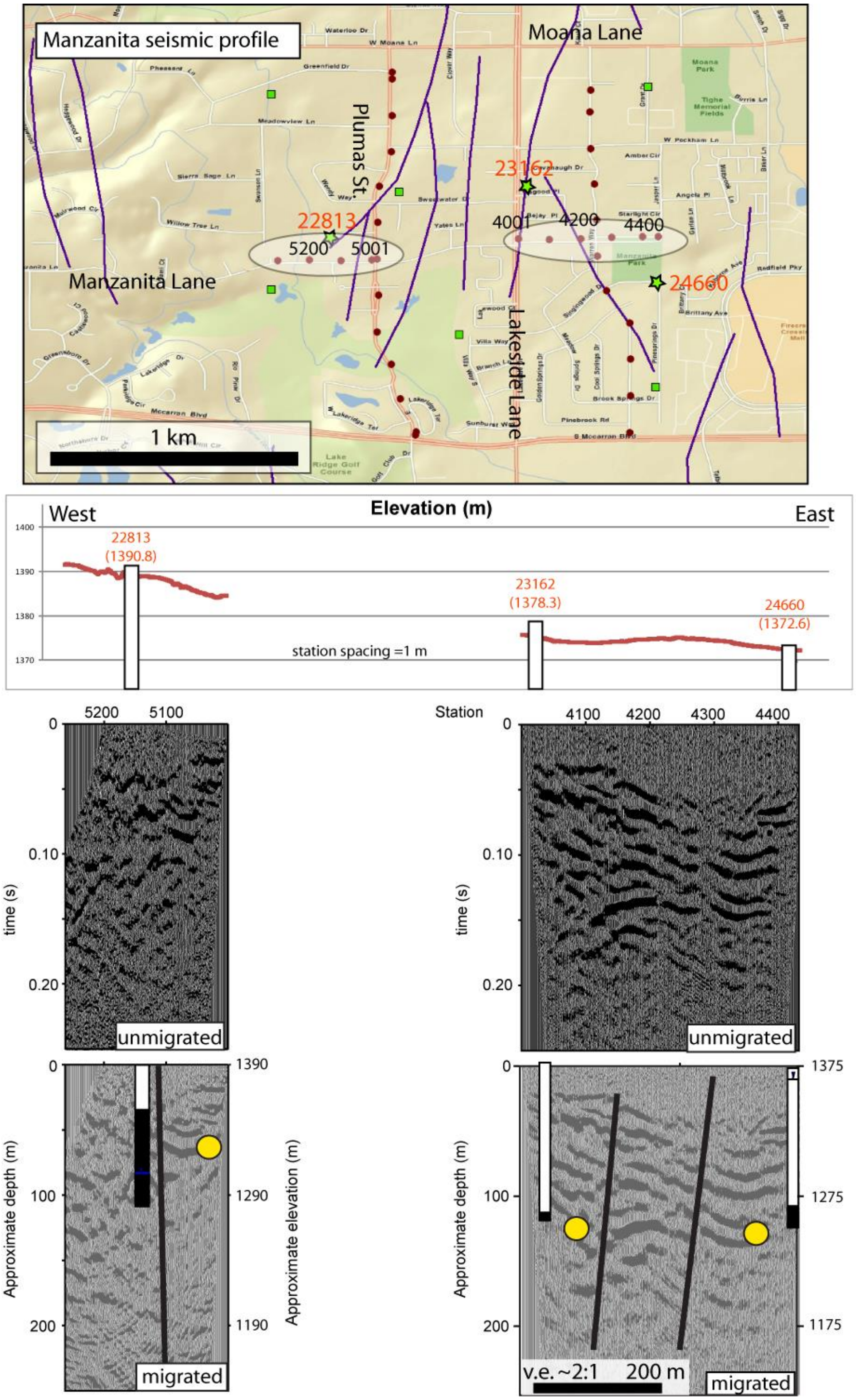

Figure 4. Manzanita Lane seismic profile location map and interpreted late Quaternary faults (Sawyer, 1999), elevation profiles, and unmigrated time and interpreted migrated depth seismic sections. Yellow dots represent interpreted bedrock surface, solid black lines are interpreted faults. Water well numbers, location and surface elevation appear on elevation profile while solid portion of water well logs on migrated profiles represent bedrock identified on driller's logs.

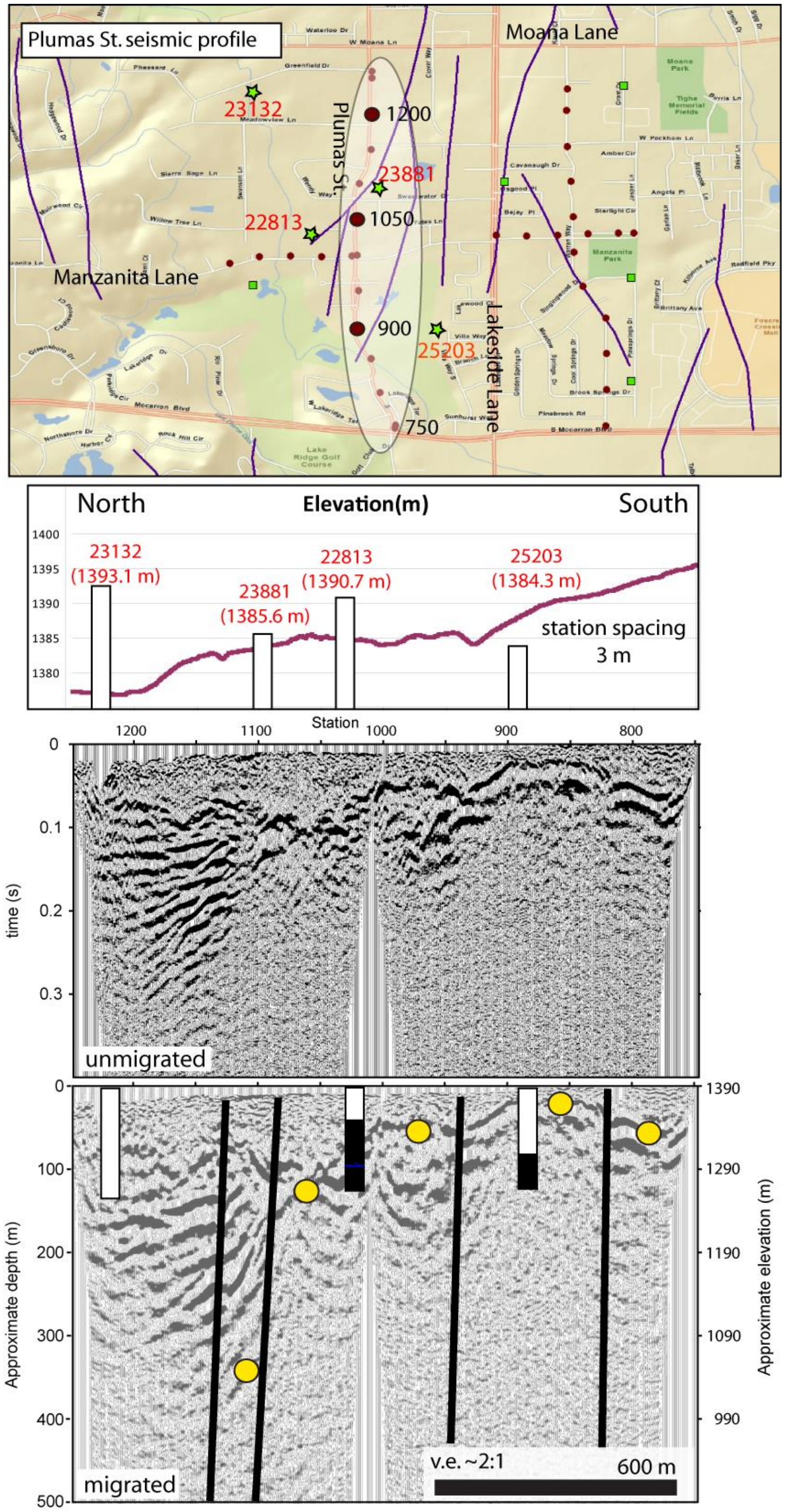

Figure 5. Plumas Street seismic profile location map and interpreted late Quaternary faults (Sawyer, 1999), elevation profile with projected water well locations (names and elevations), and unmigrated time and interpreted migrated depth seismic sections. Yellow circles represent interpreted bedrock surface and solid lines represent interpreted faults.

Warren Way Profile

The 1.4 km Warren Way seismic profile was acquired along the residential Warren Way Road south from South McCarran Blvd north to West Moana Road (Figures 1 and 6). Elevations increase to the north less than 10 m while water well data indicate that bedrock was reached at approximately 100-120 m depth along the length of the profile. The profile was acquired with 3 m source and receiver spacing using an 80 kg hitch-mounted accelerated weight drop source, 10 Hz geophones, and a 120-channel seismograph. One fault is interpreted to cross the Warren Way profile at an oblique angle near positions 3200 (Sawyer, 1999).

High quality reflection data from the upper 0.2 s two-way travel time appear along the length of the Warren Way seismic profile (Figure 6). A high amplitude reflector extends across the profile at approximately 120-150 m depth that I interpret as the top of Tertiary bedrock (yellow circles). This bedrock depth is consistent with nearby water well data that identify bedrock in four wells within a few hundred meters of the profile. Although the bedrock maintains similar depths across the profile, lateral breaks in the bedrock reflector may be related to faults or fractures. Overlying the bedrock reflector, a change from a pattern of near flat-lying reflectors along the southern portion of the profile to a zone absent of reflectors along the northern portions of the profile is observed. A gentle north-dipping reflector that surfaces near position 3200 (180 m depth at position 3450) likely represents the base of a broad fluvial channel that extends north of the limits of the seismic profile. I do not identify any faults along the length of the Warren Way seismic profile. However, fluvial processes have likely influenced deposition of late Quaternary sediments.

Discussion and Conclusions

Five seismic reflection profiles acquired in the Reno metropolitan place constraints on late Quaternary stratigraphy and geologic structures. One profile along the Truckee River, downtown Reno, shows a clear change in the stratigraphic character that extends to the upper few meters below land surface. Here, flat-lying undeformed strata typical of fine-grounded (lake) deposits are juxtaposed against laterally changing strata consistent with coarser-grained fluvial deposits. In south Reno, four seismic profiles complement existing vibroseis profiles and show offsets of late Quaternary strata that extend to near surface depths. The shallow nature of Tertiary bedrock implies long-term slip rates are difficult to estimate. However, given the quantity of faults that comprise the Mount Rose fault system, each fault strand may document a low slip rate but, when combined, may represent a significant hazard to the Reno metropolitan area.

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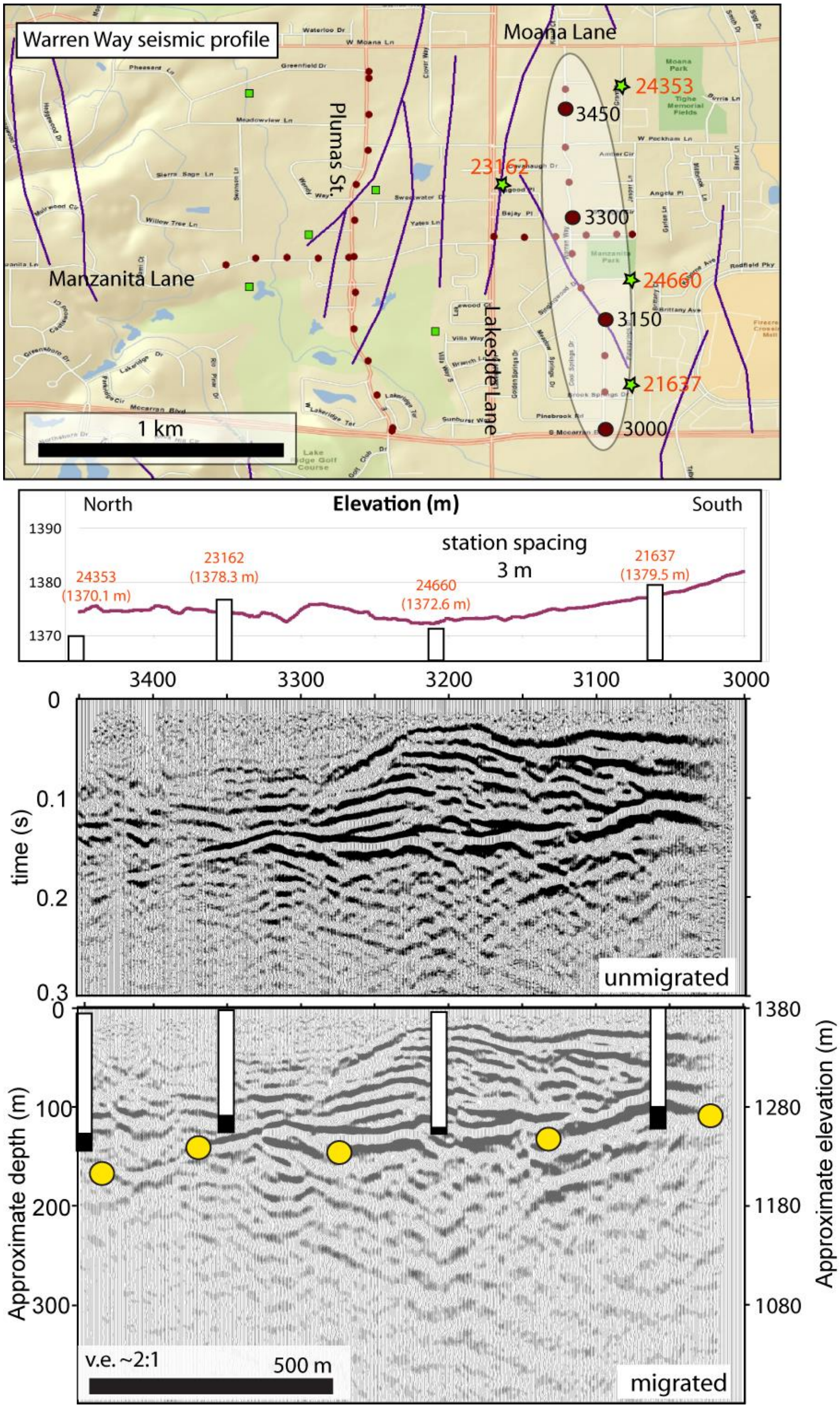

Figure 6. Warren Way Road Road seismic profile location map and interpreted late Quaternary faults (Sawyer, 1999), elevation profile with projected water well locations (names and elevations), and unmigrated time and interpreted migrated depth seismic sections. Yellow circles represent interpreted bedrock surface and solid lines represent interpreted faults.

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