Guide for the Earth Science Week Field Trip, October 21, 2017

Nevada Bureau of Mines and Geology Educational Series E-61

A land in transition! Ancient river courses, young volcanoes, recent earthquakes, and modern debris flows in the Carson Valley

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2017

LOGISTICS

The field trip starts in the parking lot of Starbucks Coffee at **3325 Retail Dr., Carson City, NV** at **9:00 AM**. We will be parked on the southern side of the parking lot, closest to Bernhard Way.

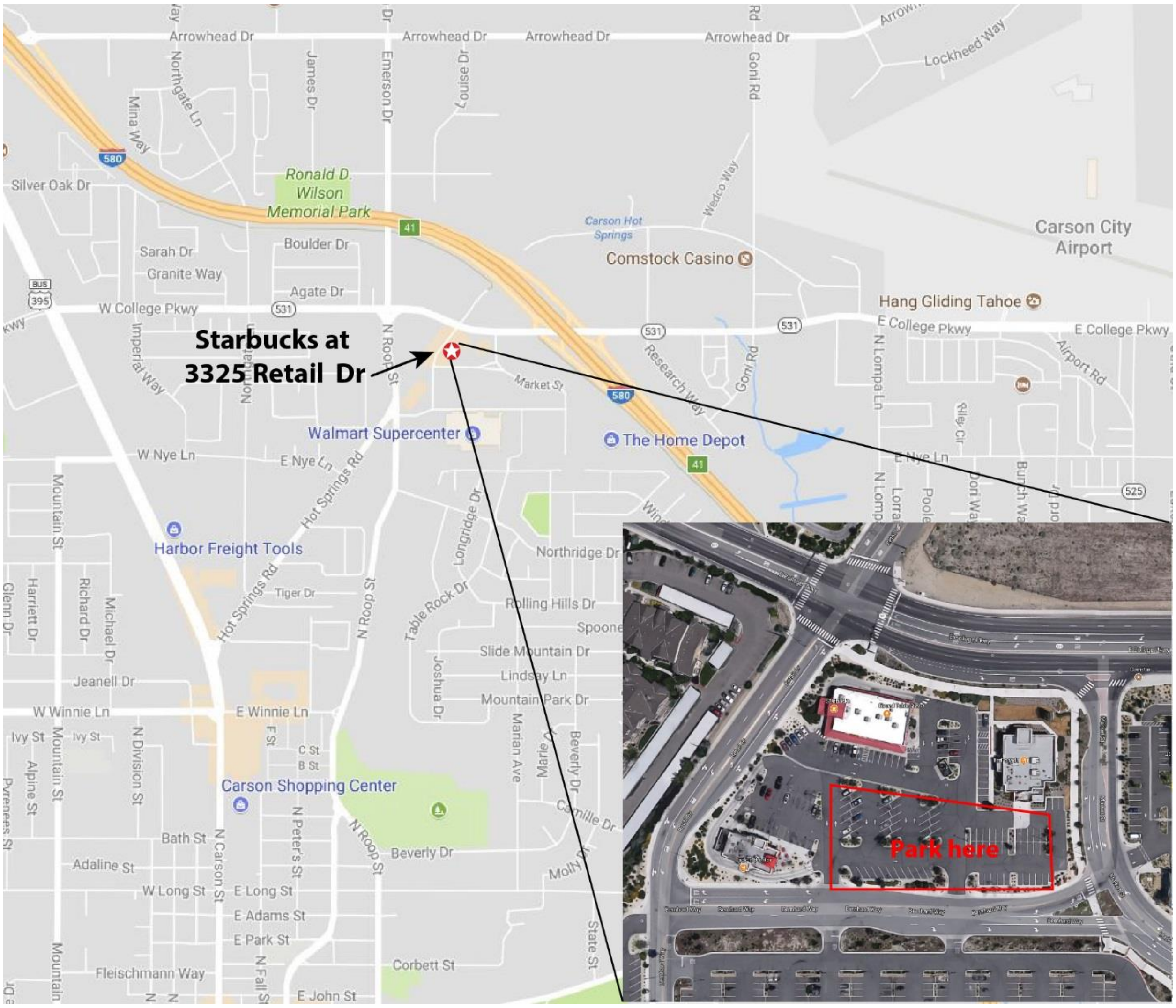


Figure 1. Field trip starting location.

We will have a brief discussion of the plan for the day and depart for the first stop by 9:30 AM.

Stops 1–3 will be accessible without four-wheel drive. Stop 4 can also be reached easily without four-wheel drive by walking on a dirt 2-track for 5–10 minutes. Those with high clearance vehicles that would like to drive closer may do so.

Road log mileage may vary depending on tire size and other factors and should be considered approximate. If you can't find the group feel free to call or text Seth Dee's cell phone number at 541-520-4146 and he will try to reply. Please bring a pack lunch, water, sturdy shoes, jacket, camera, and a big smile.

INTRODUCTION

The Carson Valley is bound to the west by the Carson Range and to the east by the Pine Nut Mountains. The east and west forks of the Carson River converge near the town of Genoa, and the river continues north-northeast through the valley on its way to the Carson Sink, 65 miles to the northeast surrounding Fallon, NV. Carson Valley is home to Minden and Gardnerville, and combined with Carson City has a population of approximately 100,000 residents.

This field trip will highlight aspects of the diverse and fascinating geology in the Carson Valley, including young and ancient volcanism, active faults, geothermal fluids, and recent debris flows.

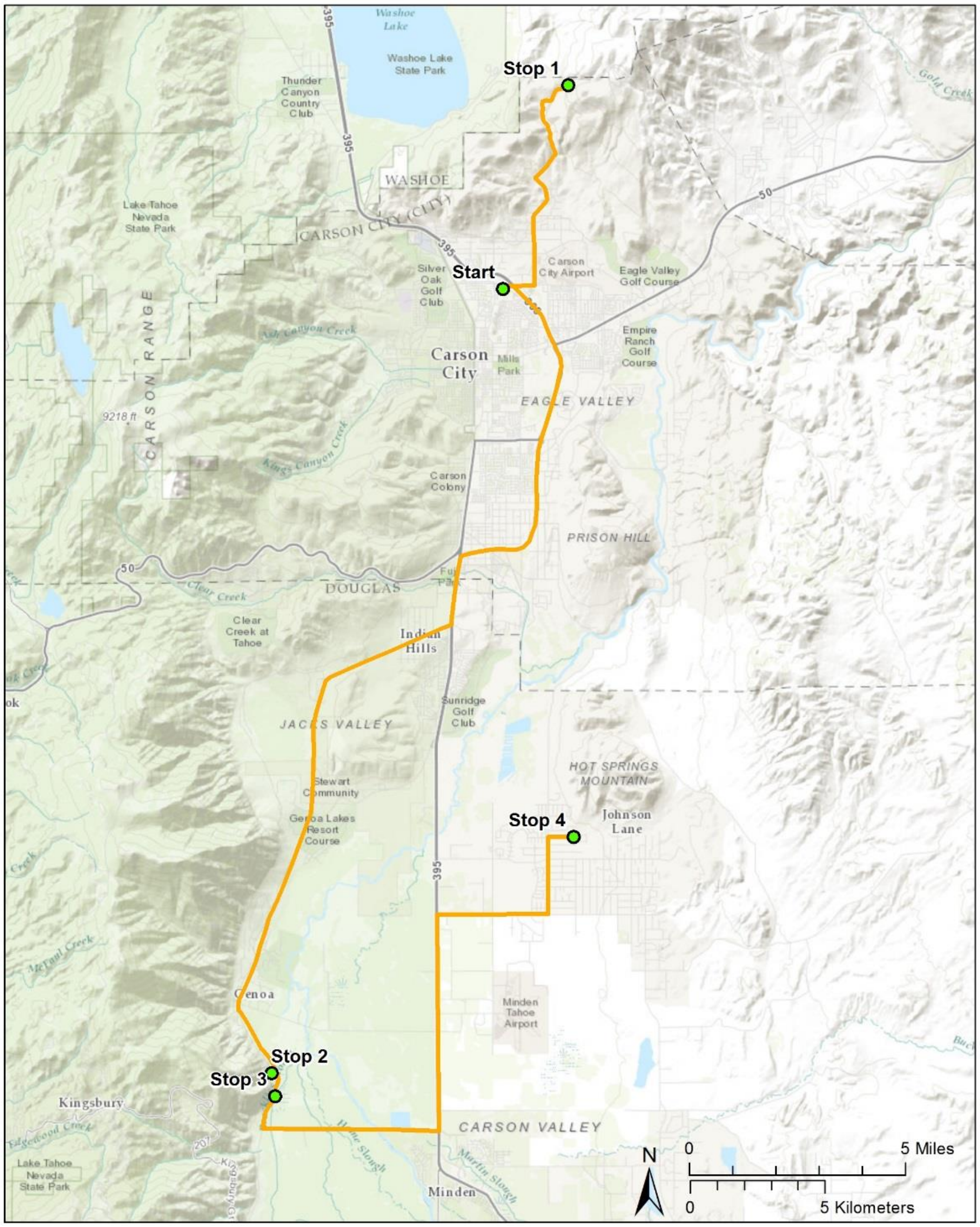


Figure 2. Map of the Carson Valley showing field trip route and stops.

ROAD LOG AND FIELD STOPS

Zero miles at the exit from the Starbucks parking lot onto Bernhard Way.

0.0 – Turn left onto Bernhard Way.

0.05 – Turn left onto Market St.

0.1 – Turn right onto E. College Parkway.

0.6 – Turn left onto Goni Rd.

1.1 – After crossing Arrowhead Drive, note the piles of "lava rock" used for landscaping materials. We will be visiting the source of these rocks shortly.

2.7 – Turn right to stay on Goni Rd. at the Goni Pit sign.

3.3 – Note the roadcuts on the left that expose Cretaceous age (~100 million years old) granodiorite (similar to granite) that is crisscrossed by aplite dikes. Granodiorite is a coarse-grained igneous rock that solidifies from magma (molten rock) several miles deep in the Earth and is typically composed of the light-colored minerals feldspar (both plagioclase and orthoclase) and quartz with much lower percentages of the dark minerals amphibole and biotite (mica). In the late stages of magma solidification, the outer shell of the granitic body fractured and the last bits of magma shot through the fractures and hardened quickly as "dikes" of aplite—a finer grained version of granite without the dark minerals.

4.9 – The road makes a hairpin turn. Park on the right side of the road at this turn for **stop 1.**

<u>Stop 1. Landscape evolution of the Carson Valley, Nine Hill paleovalley, and Quaternary cinder cone</u>

From the parking area we will walk west on a trail to an overlook of Carson and Eagle valleys with exposures of the Nine Hill Tuff.

Landscape Evolution of the Carson Valley

The Carson Valley and surrounding mountains are the result of relatively young tectonic forces. Around 6 million years ago the earth's crust in this region began to extend rapidly causing the Pine Nut and Carson ranges to form and the intervening Carson Valley to drop down. Below are the principal geologic events that impacted the landscape you see in front of you.

~125 to 80 million years ago – Subduction along the west coast of North America caused crustal melting and intrusion of a huge volume of magma into the crust. This magma crystalized into the granitic rocks of the Sierra Nevada batholith. These rocks are exposed in the Carson Range to the west and also underlie the volcanic rocks we are standing on.

~80 to 31 million years ago – Much of Nevada and eastern California was uplifted into a broad plateau often referred to as the "Nevadaplano" (a takeoff on the Altiplano of the Andes in South America). The granitic rocks of the Sierra Nevada batholith became exposed at the surface, and river systems flowed from central Nevada to the Pacific Ocean.

~31 to 15 million years ago – Volcanic eruptions occurred throughout central and western Nevada. Many of these eruptions were from calderas that produced large volumes of ash that flowed down "paleovalleys" into the Pacific Ocean. Yellowstone (about 630,000 years ago) and Crater Lake (about 7,700 years ago) are well-known and much younger examples of calderas.

~15 to 6 million years ago – Volcanoes continued to erupt throughout the region and the crust began to extend in an east-west direction. This caused local sedimentary basins to form as the "Nevadaplano" broke up.

~6 million years ago to present – The tectonics of the western edge of North America have changed progressively starting about 30 million years ago and continuing today, from a subduction zone, where an oceanic plate was driven underneath a continental plate, to a transform boundary, where the two plates were sliding past each other. This change affected the Carson Valley around 6 million years ago. The change in the plate motions caused the formation of the San Andreas Fault on the west coast of North America, and the development of the Walker Lane in Nevada and eastern California. The Walker Lane is a system of strike-slip and normal faults that collectively are like a "sister-fault" to the San Andreas. The Sierra Nevada are moving northwest relative to central Nevada and this relative motion is causing the crustal deformation, and the dramatic landscape, that you see around you.

Nine Hill Paleovalley

We are standing on the 25.3-million-year-old Nine Hill ash-flow tuff (figure 4). This rock is a mixture of volcanic ash, pumice fragments, and pieces of other rocks. The rock was erupted from a newly discovered caldera volcano in the Clan Alpine Mountains, approximately 100 miles to the east, and flowed westerly down paleovalleys that continued across the area now occupied by the Sierra Nevada to the Pacific Ocean (figure 5). At that time the coast of the Pacific Ocean was near the present location of the Sacramento Valley. Because the ash-flow tuffs flowed and were deposited in paleovalleys, mapping out the paleovalley locations is an important tool for determining the magnitude and style of faulting in western Nevada. The same ash-flow tuff deposits we are standing on are also located to the west, ~800 m higher in elevation, near the top of the Carson Range (figure 6). Therefore we know that approximately 800 m of tectonic displacement has occurred on the Carson range-front fault system since the deposition of the tuffs.

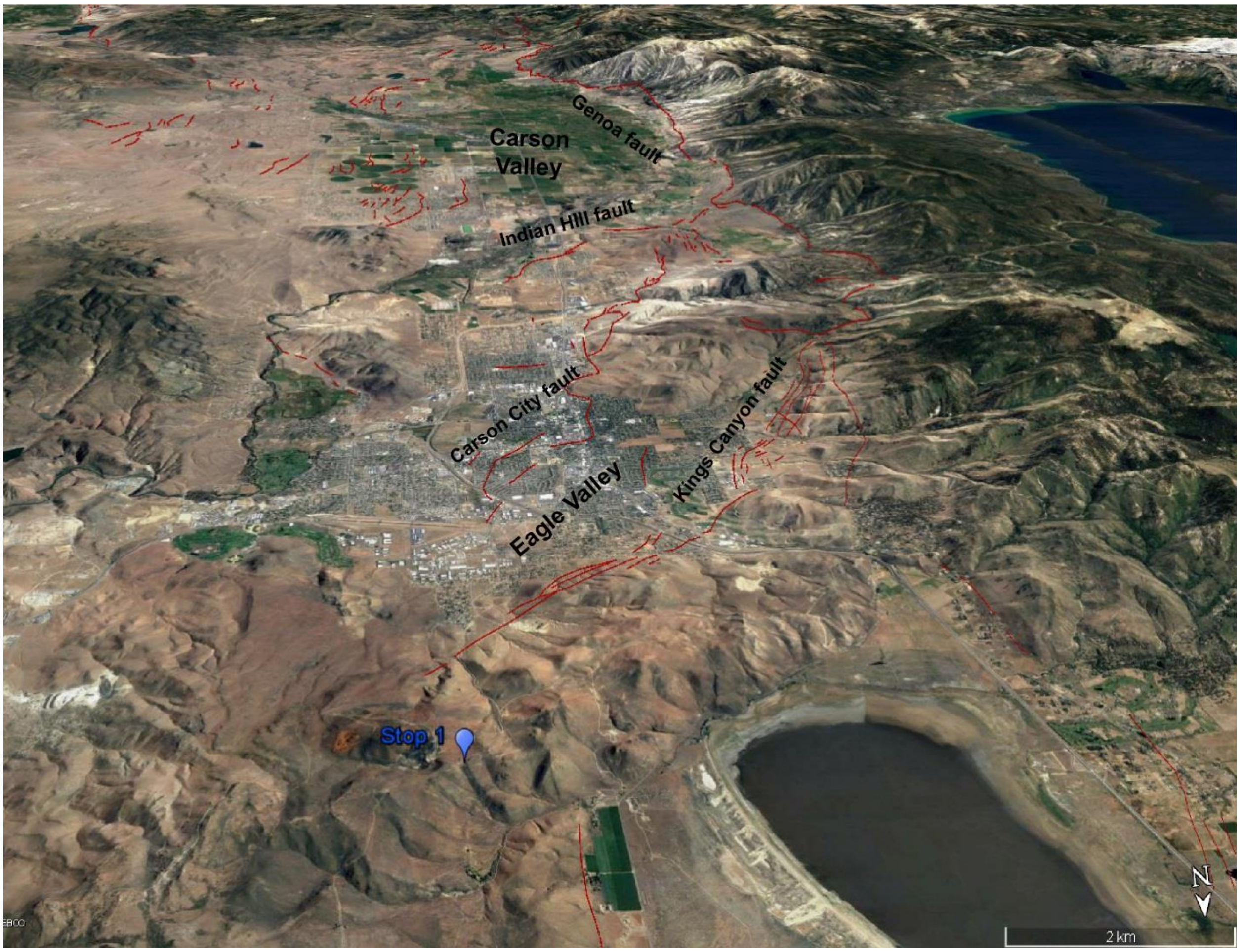


Figure 3. Oblique view looking south at Carson and Eagle valleys, showing active faults from the USGS Quaternary fault database. Displacement on these faults created much of the modern topography in the Carson Valley. (image from Google Earth)

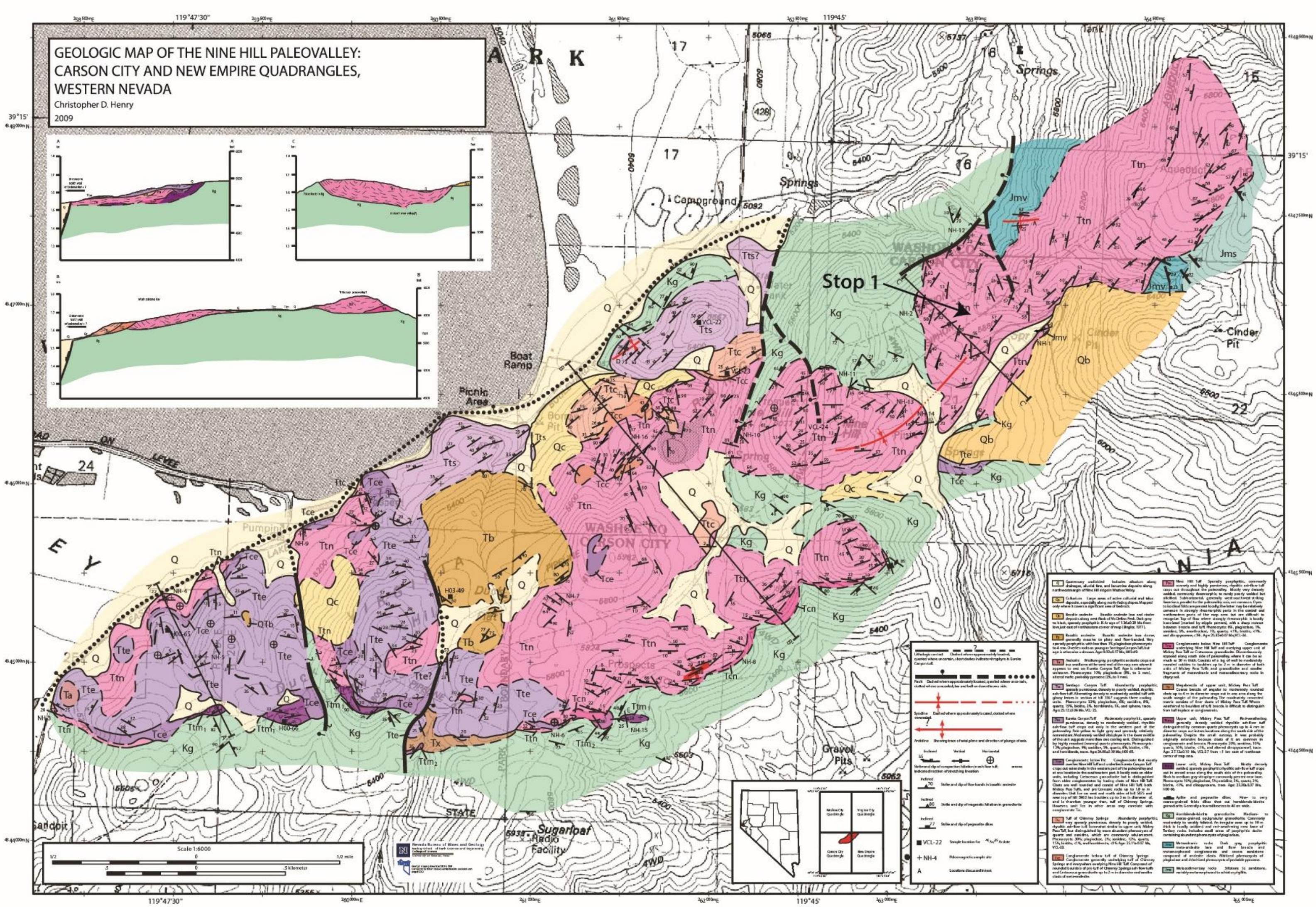


Figure 4. Geologic map of the Nine Hill paleovalley (from Henry and Faulds, 2010).

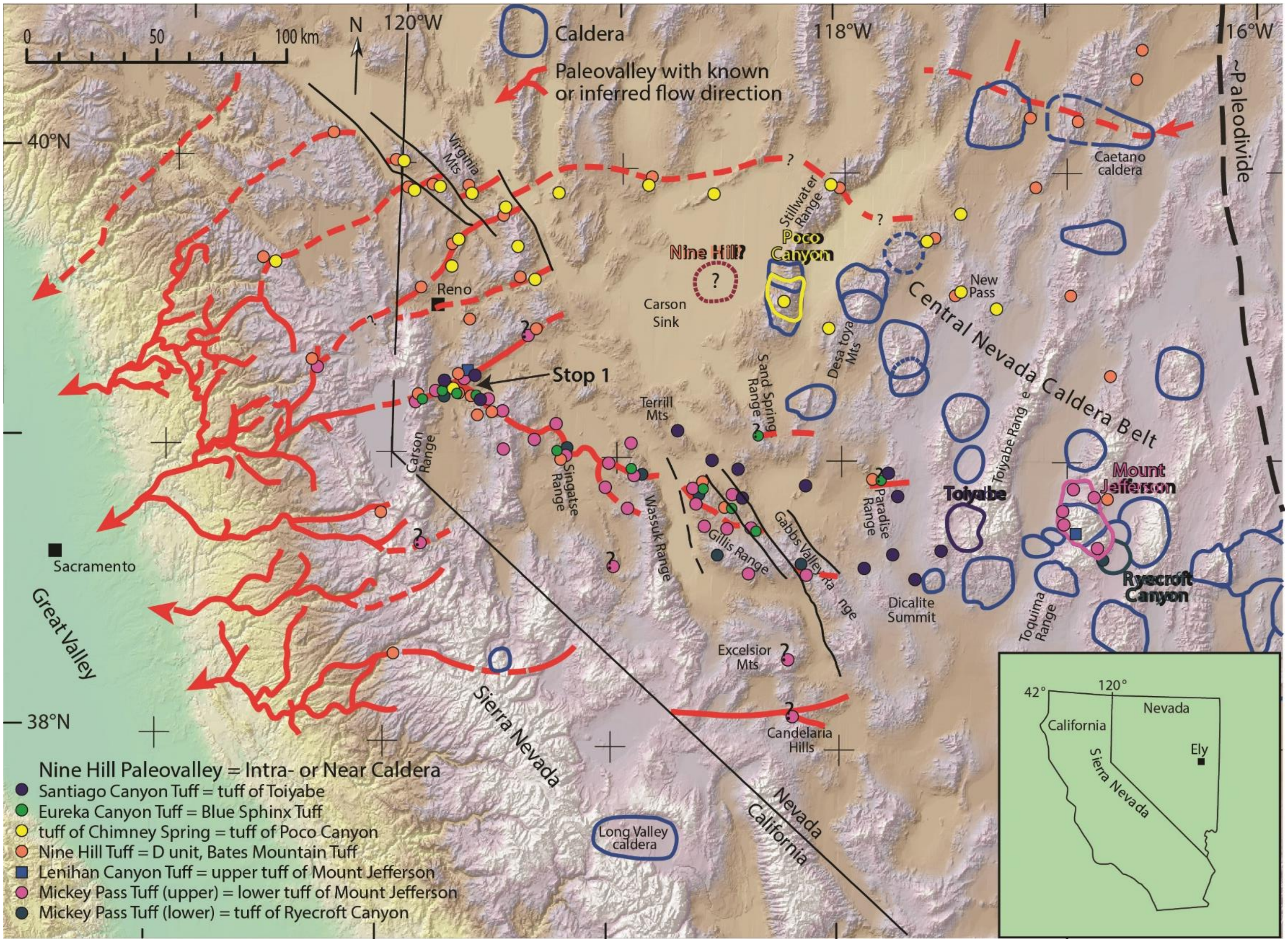


Figure 5. Digital elevation map of the western Great Basin showing the distribution of known paleovalleys (from Henry and Faulds, 2010).

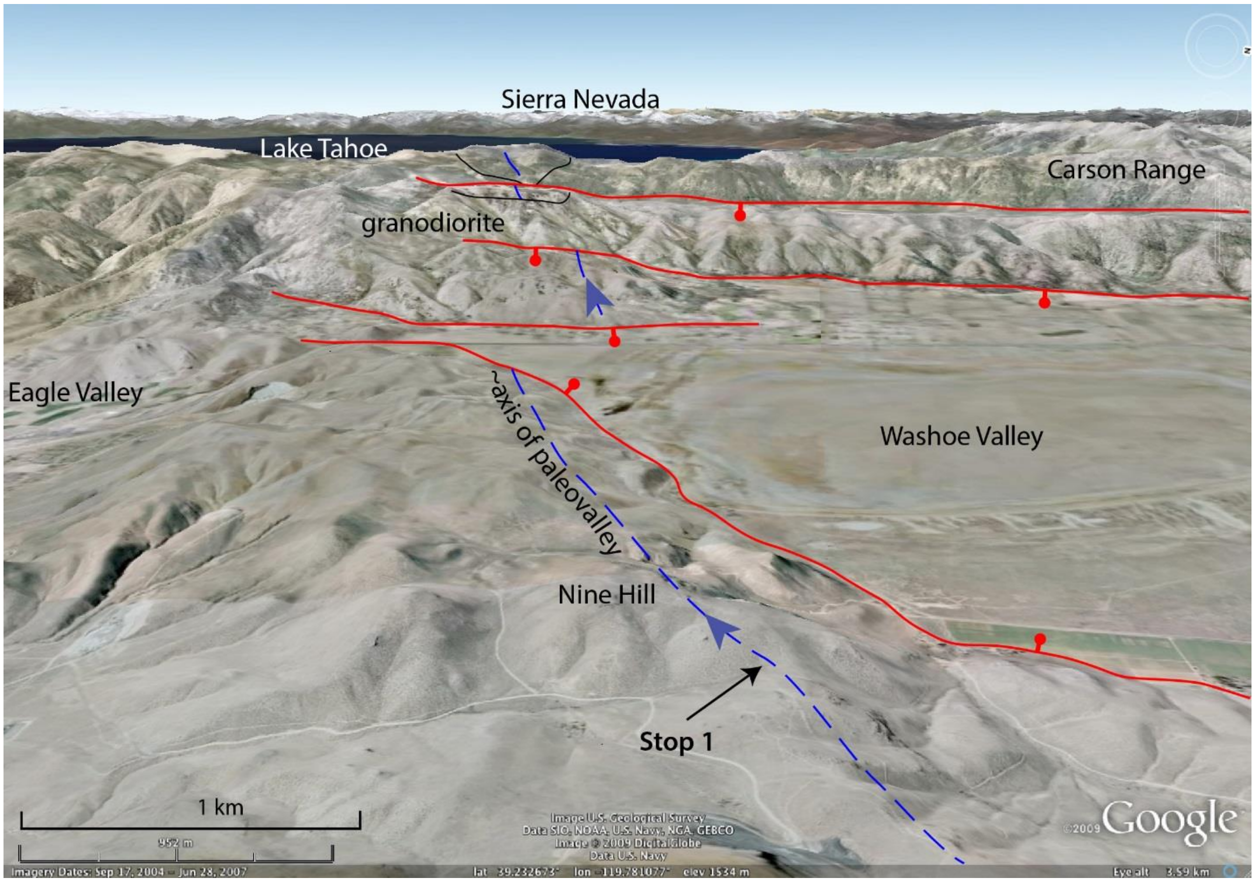


Figure 6. View to west down axis of Nine Hill paleovalley across the Carson Range, showing range-front faults, paleovalley in the Carson Range, and the fault along the northwest edge of the paleovalley.

Quaternary Cinder Cone

From the stop 1 lookout, you see the Cinderlite quarry to the east. The quarry operation is excavating cinder deposits from the vent of a 1.4-million-year-old volcano of the McClellan Peak Basalt (figure 7). The rock surrounding the vent is primarily basaltic andesite scoria which is highly vesicular (full of holes) and was ejected rapidly during the volcanic eruption. Basaltic andesite is a variant of basalt; geologists are enamored with obscure names as physicians. The erupted lava started at great depth and degassed as it rose to the surface, causing gas pockets to be preserved in the rock as it cooled in mid-air. Cinder cone eruptions are common on the Big Island of Hawaii (figure 8).

The cinders at this stop are black. Cinders in a quarry on the east side of McClellan Peak vent are red because iron, which is abundant in basaltic rocks like the McClellan Peak Basalt, is oxidized, much like rust on a cast iron railing. Both black and red cinders are used as decorative stone.

Figure 7. Google Earth view to the north of the McClellan Peak volcanic vent.

Figure 8. 1985 cinder cone eruption in Kilauea, Hawaii (Photo from http://volcano.oregonstate.edu/cinder-cones).

The volcanic rocks of the cinder cone lie stratigraphically on top of the volcanic rocks of the paleovalley and also on older sedimentary rocks downhill to the south at the north edge of Carson City (figure 7). Two basalt lavas flowed down from the vent area here at stop 1, around hills of the sedimentary rock, and into the northern edge of what is now Carson City. The eastern flow even crossed what is now Highway 50 (the Lincoln Highway). This shows that the topography of the northeastern part of Eagle Valley 1.4 million years ago was much like it is today, even though a lot of faulting has occurred along the west side of the valley. The McClellan Peak volcano is extinct, and there is no evidence that it will ever erupt again.

The Nine Hill Tuff and other tuffaceous volcanic rocks of the paleovalley are very different volcanic systems than the basalt cinders and lavas. The tuffs are major parts of extremely voluminous igneous activity during subduction, when the oceanic plate west of North America dove beneath North America. The tuffs are chemically like the granitic rocks of the Sierra Nevada batholith, and the volcano calderas in western and central Nevada are underlain by batholiths that were the source of the tuff eruptions. The volcanic eruptions that formed the tuff deposits were probably violent, explosive eruptions that sent out lateral blasts of superheated ash, pumice, pulverized rock and gases: you would not want to be nearby when these were happening. The basalts on the other hand result from the extension and faulting that are now occurring in western Nevada and throughout much of western North America. Steamboat Hills at the south edge of Reno are another example of very young volcanism related to the extension. Basaltic-type volcanic eruptions are usually much less explosive than the tuffs. Soda Lakes near Fallon are the youngest local volcanoes in this area; they erupted after 10,000 years ago and possibly as recently as 1,500 years ago. Either way, Soda Lakes probably erupted when early humans lived here. The basalts and volcanic rocks of the Steamboat Hills and Soda Lakes are tiny in volume compared to the tuffs and batholiths.

However, there is a small chance that more eruptions could occur in the Reno area. Think of what a great tourist attraction that would be.

Following this stop we will head back down Goni Rd.

4.9 – Head south down Goni Road.

9.2 – Turn right on E. College Parkway.

9.6 – Merge onto I-580 South.

15.8 – Turn left (south) onto US-395.

17.1 – Turn right onto Jacks Valley Road. As you travel south on Jacks Valley road note the steep eastern range front of the Carson Range. This range front is the result of tectonic displacement on the Genoa fault, which has uplifted the Carson Range, and down-dropped the Carson Valley through repeated surface rupturing earthquakes. At our next stop we will get to put our hands on the fault responsible for all this action (and beautiful scenery!).

25.9 – Pass through the town of Genoa home of the Mormon Station Historic Park. Mormon Station was founded in 1851 and is considered to be the first permanent non-native settlement in Nevada. The settlement was renamed Genoa in 1855. The Genoa Bar & Saloon is the oldest continuously operating bar in Nevada.

27.1 – Turn right into a gravel parking area at an abandoned quarry.

Stop 2. Genoa Fault

At this stop we will look at a beautiful exposure of the Genoa fault surface and discuss evidence for recent surface rupturing earthquakes along the fault.

The Genoa fault is one of the most active normal faults in the Basin and Range Province. A normal fault drops rock on one side of the fault down relative to the other side (figure 9).

The fault surface at this stop has been exposed by quarrying of the Quaternary alluvial fan gravels in the hanging wall of the fault. These gravels were faulted against the Cretaceous granodiorite in the footwall by repeated earthquakes (figure 10). We can evaluate the type of motion on the fault by looking carefully at the fault surface which has vertically oriented striations (scratches) and mullions (grooves). This tells us that the recent motion on the fault was "dip-slip," meaning that the hanging wall moved down the dip direction of the fault surface. Many other active faults in the region have oblique motion, which means motion on the fault is a mix of dip-slip and strike-slip.

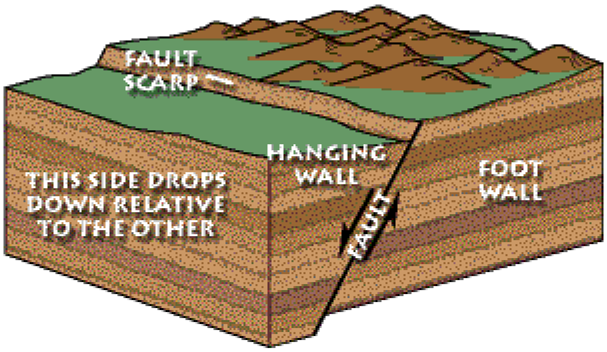


Figure 9. Schematic diagram of a normal fault.

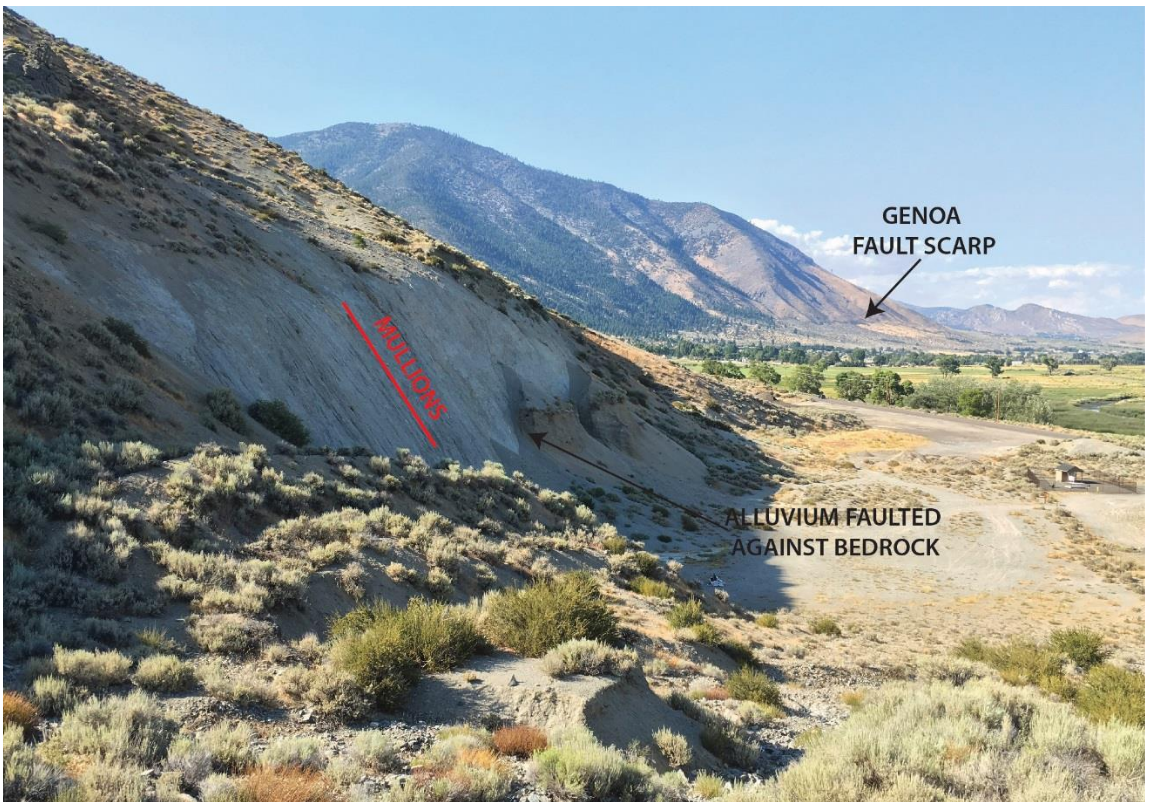


Figure 10. Photo looking north at stop 2 showing orientation of the dip-slip mullions in the Genoa fault surface, alluvium faulted against bedrock, and the prominent Genoa fault scarp in the distance.

There are two common ways that geologists evaluate how recently a fault has been active; this allows for the characterization of the fault hazard. The first is by mapping the location of the fault scarp and determining the age of the faulted deposits (figure 11). On the figure 11 map, the youngest deposit shown to be faulted by the Genoa fault is Qay_1, which is described as late to middle Holocene alluvial fan deposit. This means that the fault has had a surface rupturing earthquake since the middle Holocene— about 7,000 years ago.

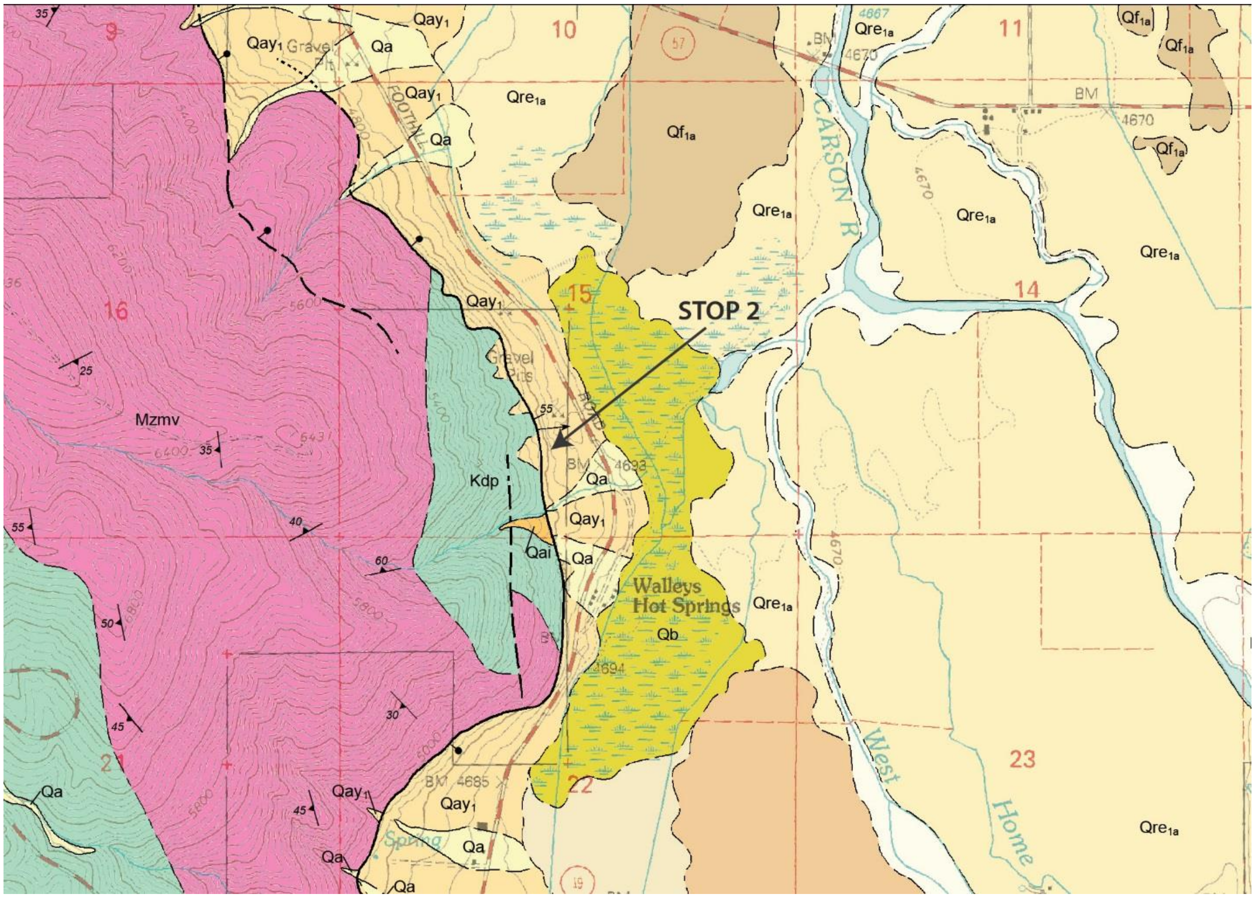


Figure 11. Stop 2 shown on the geologic map of the Minden quadrangle (Ramelli et al., 2014).

To get a more precise understanding of the fault history, geologists will often dig a paleoseismic trench across the fault. Ramelli et al. (1999) dug a trench across the prominent faults scarp just south of stop 2. They recorded evidence in the trench of two earthquakes that faulted young alluvial-fan deposits (figure 12). They dated organic materials in the faulted sediment in the trench, but the ages were too young to be realistic and were determined to be reworked material, possibly from plant roots. However, neighboring trenches on the same fault showed evidence for the same two earthquakes and yielded more accurate ages, suggesting that the two recent earthquakes occurred approximately 500–600 and 1,770–2,700 years ago.

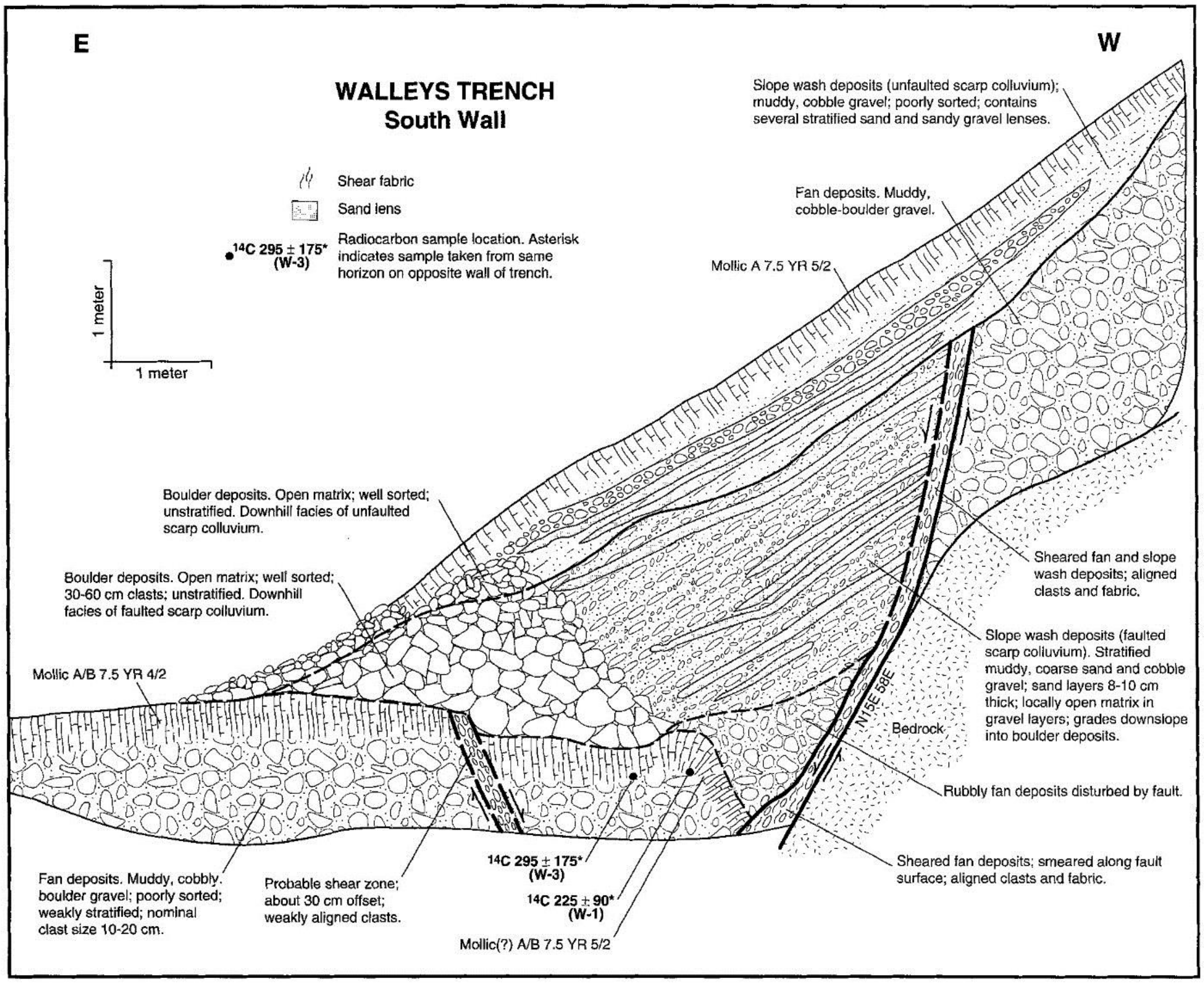


Figure 12. Log of the trench across the fault scarp near stop 2. The trench exposed alluvial-fan deposits displaced by more than 8 meters during two earthquakes.

We will now leave stop 2 and drive to the south side of Walley's Hot Springs Resort just down the road. **We cannot occupy this site until after 1:00 PM!**

27.1 – Turn right onto Foothills Road.

27.6 – Turn left into a driveway on the south side of Walley's resort, take your first right in the parking lot and park in the gravel pullout by the grassy field.

<u>Stop 3. Walleys Hot Springs</u>

This stop is adjacent to Walley's Hot Springs Resort and provides a suitable setting to discuss geothermal systems.

A geothermal system has three key components: a heat source, a fluid to transport the heat, and permeable pathways that allow the fluid to move the heat around (e.g. open fractures in the rock). Almost anywhere on the earth, it gets hotter the deeper we go into the earth. However, the rate at which it gets hot varies depending on the geological setting and tectonic environment. The average geothermal gradient (rate of temperature change with increasing depth) for continental lithosphere (i.e. land) is approximately 25 degrees Celsius per kilometer (°C/km). However, in some places, geothermal gradients can be much higher, e.g. 100 °C/km and we find warm or high temperatures at shallow depths. For example, in places where we have active volcanoes (e.g. Yellowstone National Park) or magmatic intrusions (that have not erupted at the surface), fluids (water and steam) may be boiling (100 °C; 212 °F) at the surface, bubbling up in hot springs, geysers and mud pots. The Great Basin region is home to many geothermal systems that range in temperature from ~40 °C to over 200 °C. These systems source their heat from either magmatic intrusions, and/or high heat flow that is characteristic of the region (figure 13).

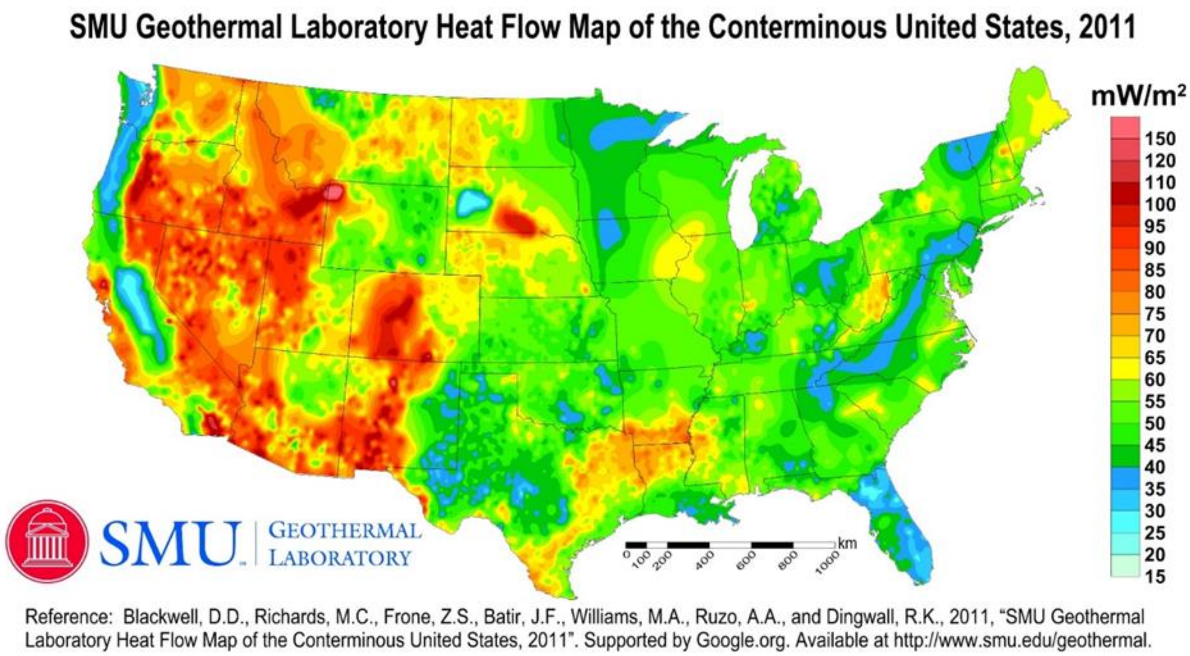


Figure 13. Heat flow map of the USA.

The elevated heat flow across the Great Basin (and much of the western USA) is thought to result from stretching and extension of the continental crust in this region over the last 17 million years (Dickinson, 2006). This stretching resulting in upwelling of the molten mantle that underlies our continents and oceans, bringing more heat to shallow depths. In addition to the high heat flow, and associated with the stretching of the Great Basin, the region is characterized by many active faults that have created the basin (valleys) and range (mountains) features that we observe in Nevada and Utah. Movement on these faults creates fractures that act as conduits for fluids, and allow warm-hot geothermal fluids to migrate towards the surface. Some fluids will reach the surface (as at Walleys Hot Springs) (figure 14), and others may mix with cool groundwater and reach the surface further away from the range front (figure 15). Work conducted by the Nevada Bureau of Mines and Geology (Cashman et al., 2012; Faulds and Hinz, 2015) indicates that the majority of known geothermal systems in Nevada are associated with areas where complex fault geometries occur, and the faults are active (i.e. have slipped in the last 10,000 years or less). It is believed that these complex fault geometries and interactions support the creation of open fracture pathways, and in combination with regular fault movements to keep existing fractures open as well as create new fractures, these provide the essential pathways for geothermal fluids to migrate upwards.

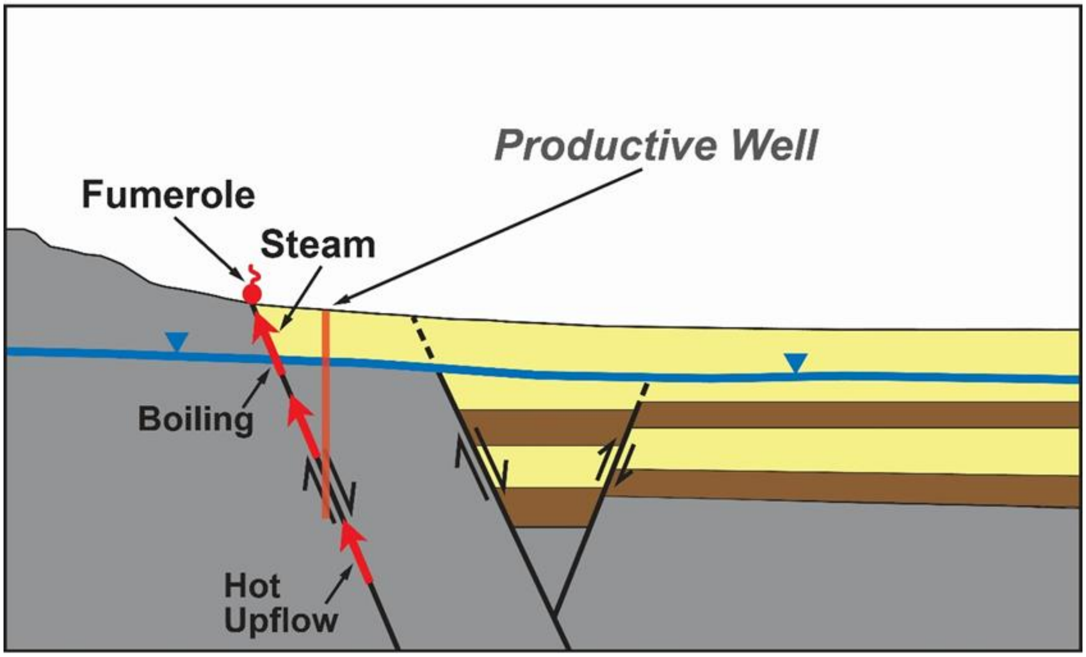


Figure 14. Conceptual models geothermal systems 1.

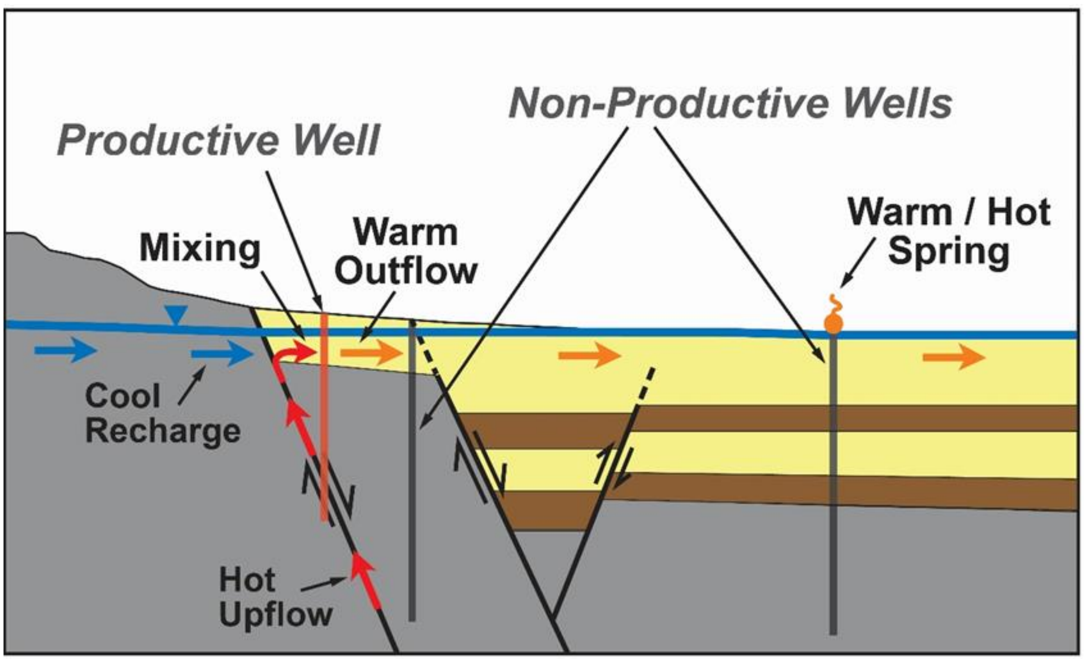


Figure 15. Conceptual models geothermal systems 2.

To be useful for commercial electric power production, geothermal resource temperatures must be at least 130 °C. Resource temperatures lower than this are still useful: the heat can be used for other applications, e.g., drying vegetables, heating buildings and swimming pools, and hot springs/bathing. In Nevada, we produce approximately 8% of our electricity from geothermal resources, with around 700 MegaWatts (MW) installed capacity. Additionally, we have many hot springs sites that are suitable for bathing.

Geologists use a variety of tools to explore for and characterize geothermal systems: we measure the temperature of hot springs, and the sub-surface temperatures using shallow temperature probes (e.g., 2 meters), deeper water wells, mineral exploration holes, or thermal gradient wells (100's of meters). Additionally, we measure the geochemistry of hot spring or well fluids: this can tell us where the fluid came from, how much the fluid has interacted with the rock, provide some indications of age, and also how hot the fluid once was. Several chemical species (e.g. sodium (Na), potassium (K), magnesium (Mg), silica (SiO_2), chloride (Cl), sulfate (SO_4), boron (B), lithium (Li) and fluoride (F) and isotopes of oxygen (^{18}O) and hydrogen (deuterium: ^{2}H) are usually sampled and analyzed. In locations where we have no hot springs or wells to sample, geologists will use geophysical data (e.g. gravity surveys, magnetotelluric or seismic reflection profiles) to evaluate an area and assess whether there is potential for geothermal resources to occur.

Walley's Hot Springs spa and luxury hotel was built in 1862 by David and Harriet Walley at a cost of more than $100,000. Walley's had a 40-room hotel with 11 bathrooms, a grand ballroom, a large stable, a swimming pool, and several bathhouses with a resident physician and masseur. After a long history and many changes in ownership, the spa and restaurant were acquired by Summerwinds Resort Services, LLC in 2010. Summerwinds recently changed the name to "1862 David Walley's Hot Springs Resort and Spa" to honor David and Harriet Walley's vision of 150 years ago.

Figure 16. Outflow channel from Walleys Hot Springs (man-made).

The springs discharge at the surface at a temperature of 65°C (150°F) (figure 16). Several shallow thermal gradient wells have been drilled around the springs, and they show a thermal anomaly where temperatures are as high as 75 °C at 30 meters depth. The highest temperature measured is 83 °C from a well that is 384 meters deep. The waters are relatively fresh with low total dissolved solids (< 500 parts per million (ppm): most geothermal fluids are derived from rainfall that has percolated and circulated in the sub-surface over thousands to tens of thousands of years. The location of Walleys Hot Springs coincides with the recently active Genoa fault: it is likely that movement on this fault has created the fracture pathways that allow hot water to migrate to the surface. Notice that Walleys Hot Springs also occurs on a bend of the Genoa fault: stresses in the rock can be concentrated at these locations along a fault, which may favor the creation of open fractures during fault movement.

We will now head to our last stop, on the northeast side of the Carson Valley in the Johnson Lane neighborhood of Minden.

27.7 – Turn left out of Walleys and head south on Foothills Road.

28.3 – Turn left onto Muller Lane. Cross the West and East Forks of the Carson River.

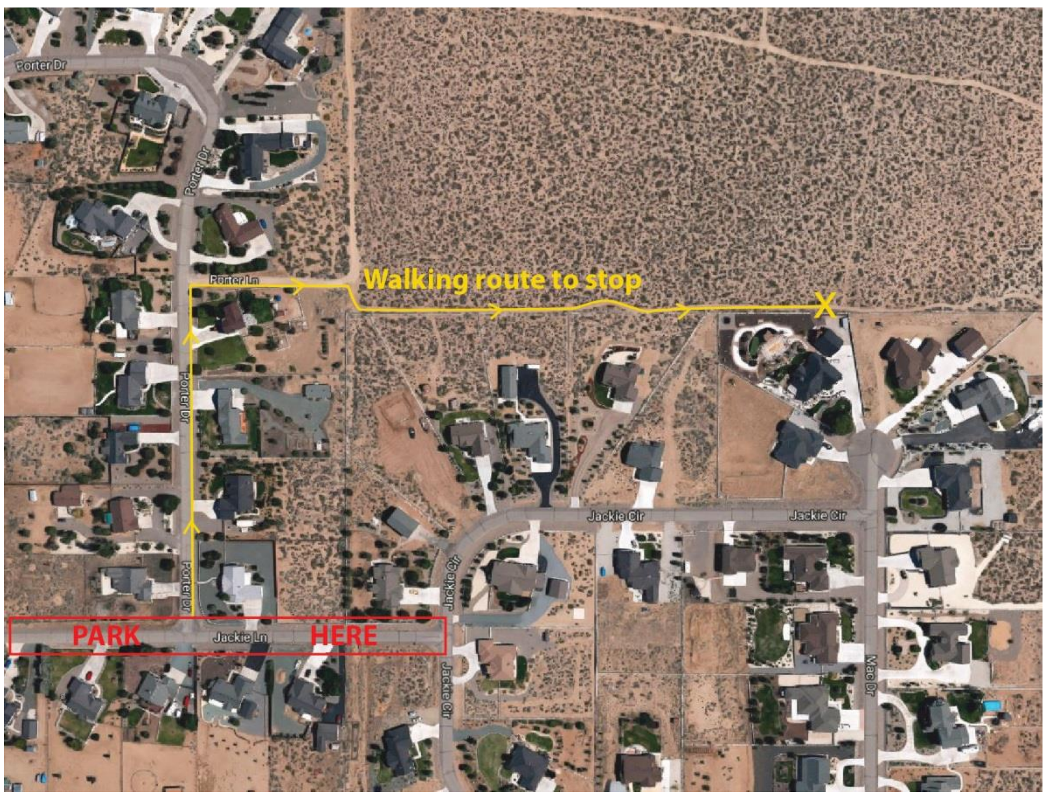
31.5 – Turn left onto US-395. **Caution**: **traffic on 395 moves very fast through here!** It may take some time to make the left turn and the caravan will likely get broken up. We are headed to the intersection of Porter Dr. and Jackie Ln, Minden, NV, for those of you using a GPS or Google maps to navigate.

36.4 – Turn right onto Stephanie Way.

38.4 – Turn left onto Vicky Lane.

38.8 – Turn right onto Jackie Lane.

39.2 – Park near the intersection of Jackie Ln. and Porter Dr. Use the shoulders on either side of Jackie Ln.



From the parking area we will walk north on Porter Dr., and take a right on a dirt access road that leads to our next talk location (see map).

Stop 4. Site of the 2014 Hot Springs Mountain flood and debris flow

At this stop we will look at the deposits from a flood and debris flow that occurred on July 20, 2014, when an intense burst of monsoonal precipitation centered on Hot Springs Mountain and the Johnson Lane neighborhood (figure 17). Runoff from the rainfall affected much of the neighborhood but was particularly destructive to the homes built on alluvial fans on the south Side of Hot Springs Mountain. (figures 18 and 19). Intense rainfall onto the small catchments on Hot Springs Mountain caused deep gully erosion into eolian (windblown) sand deposits. This sand mixed with boulders eroded from gullies to create a debris flow "slurry." A slurry is a mix of water and sediment that can become very dense, and can entrain and transport large boulders. Boulder levees along the margins of the flooded channels are evidence that the July 20, 2014 flood was at least partly a debris flow (figure 20).

We will walk the remnants of the flood deposit and discuss the process of flooding and debris flows on alluvial-fan deposits. Even though the flood only occurred three years ago, the deposits are already very subdued, highlighting one of the challenges of predicting flood hazards on alluvial fans.

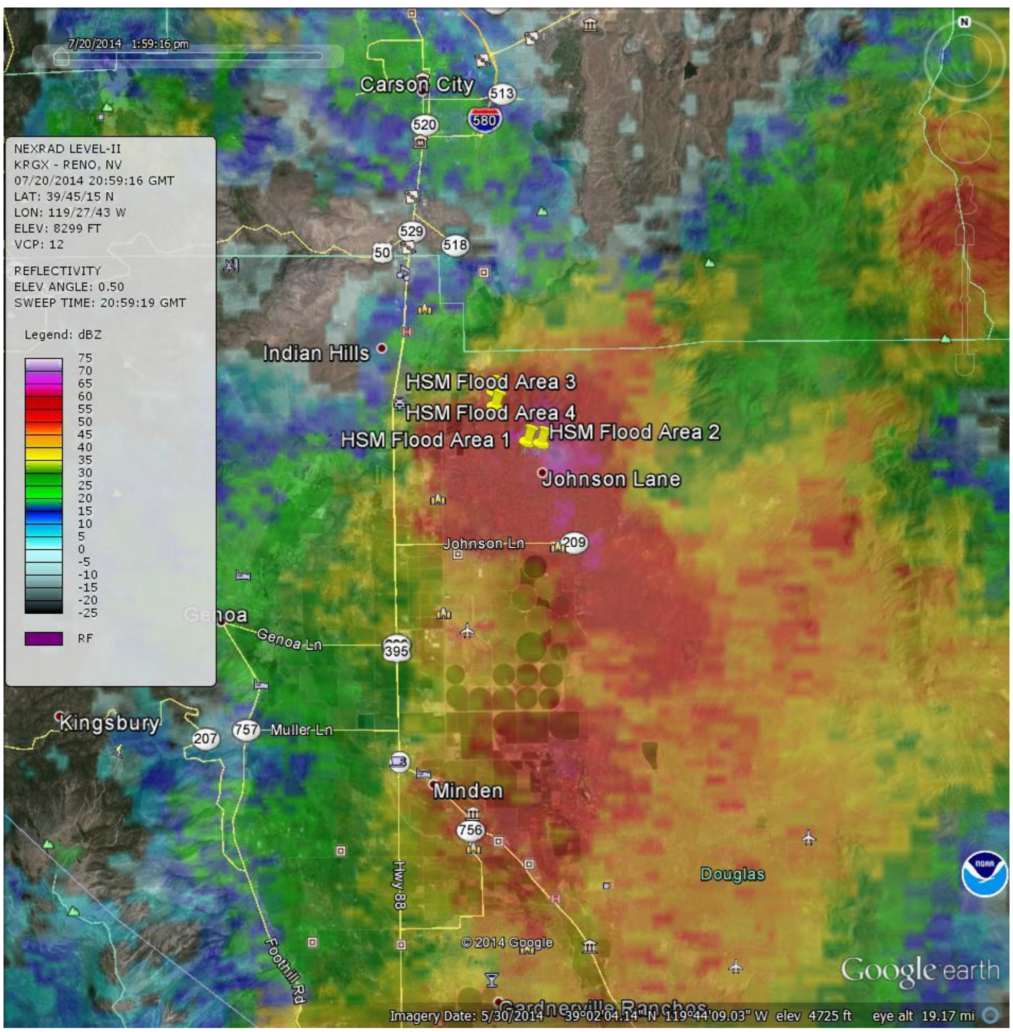


Figure 17. NEXRAD Doppler radar data showing reflectivity of the July 20, 2014 monsoonal rainfall event that triggered flash flooding near Minden, NV. The high intensity rainfall was localized over small catchments on Hot Springs Mountain.

Figure 18. Flood deposits from a July 20, 2014 flash flood that impacted the Johnson Lane neighborhood of Minden, NV (*photo from John Bell*). The flash flood avulsed the principal channels on the alluvial fan depositing large volumes of sand and debris flow deposits across portions of the fan surface, damaging several homes.

Figure 19. Sandy debris deposited around houses on Mac Dr. after the July 20, 2014 flood.

Figure 20. Fresh boulder levees near the distal end of the July 20, 2014 Hot Springs Mountain debris-flow deposit.

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Ramelli, A.R., Yount, J.C., John, D.A., and Garside, L.J., 2014, Geologic map of the Minden quadrangle, Douglas County, Nevada and Alpine County, California: Nevada Bureau of Mines and Geology Map 182, scale 1:24,000, 8 p.

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