Fall colors along the Truckee River, Storey County, Nevada

Guide for the Earth Science Week Field Trip, October 16, 2021
Nevada Bureau of Mines and Geology Educational Series E-71

A Tale of Three Rivers

and the Rapidly Evolving Landscapes of Western Nevada

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Front cover photograph by Rachel Micander.
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Logistics

The field trip starts and ends at the Great Basin Science Sample and Records Library / Publication Sales and Information Office, which we will refer to as the ***Gold Building*** throughout this guidebook. To navigate to the Gold Building from downtown Reno, take US-395 North to Exit 71 for Dandini Boulevard. Follow Dandini Boulevard east, veer right onto Raggio Parkway, and the Gold Building will be on your left. The address is **2175 Raggio Parkway, Reno, NV 89512**.

Please plan to arrive at the Gold Building parking lot by **8:00 am**. Following some introductory comments, route plans, and discussion, we will depart by **8:30 am**. We will mostly be traveling on paved highways and roads and some gravel parking areas; however, one stop is at the end of a good dirt road**,** where a high clearance vehicle would be helpful.

GPS coordinates are provided for each point of interest along the route and for all of our fives stops. All GPS points are provided in latitude and longitude in the WGS 84 coordinate system. Please bring a mask, pack lunch, water, sturdy shoes, appropriate gear, camera, hand sanitizer, and a smile.

Introduction

This year, Earth Science Week is celebrating the theme "Water Today and for the Future". In keeping with the theme, our 2021 field trip will take us on a tour of our three rivers here in western Nevada starting with the Truckee River and ending along the banks of the west fork of the Walker River in Wilson Canyon. We will discuss the geology and ecosystems along each of these rivers and their surrounding watersheds, geothermal energy production, past mining activities, landscape evolution, and natural hazards. We will also learn about the history of Buckland Station, Fort Churchill, and Mason Valley.

Our first stop will be along the Truckee River near USA Parkway. Here we will learn about the river that provides water to the Truckee Meadows and all communities downstream. We will explore past and present flooding, river terraces and geomorphology, and flora and fauna in addition to talking about river restoration and the Tahoe-Pyramid trail.

Following our stop along the Truckee River, we will wind up through the Virginia Range along USA Parkway (State Route 439). Notice the road cuts, wild horses, and new developments as we drive along this stretch of road. We will pass though the Ramsay mining district, where remains of mining activities are visible along the road. After dropping down into Churchill Valley, we will stop at Buckland Station along our second river of the day—the Carson River. Here, we will discuss the differences between the Truckee and Carson rivers, water usage, and the history of Buckland Station and Fort Churchill. There are picnic tables and pit toilets at this stop, so we will plan for an early lunch here. We will then continue on to the Thompson Smelter site near Wabuska for a detailed discussion of the rich mining history of Mason Valley, geothermal energy, and agriculture.

After exploring the Thompson Smelter site, we will continue on to the Yerington Mine and large open pit. Here we will review copper mining in Mason Valley and some of the detailed geology that makes this region rich in natural resources. We will end our day along the west fork of the Walker River in Wilson Canyon. Here, we will chat about paleovalleys, volcanic deposits, recent earthquakes, the evolution of the Walker River and the unusual ecosystems it creates.

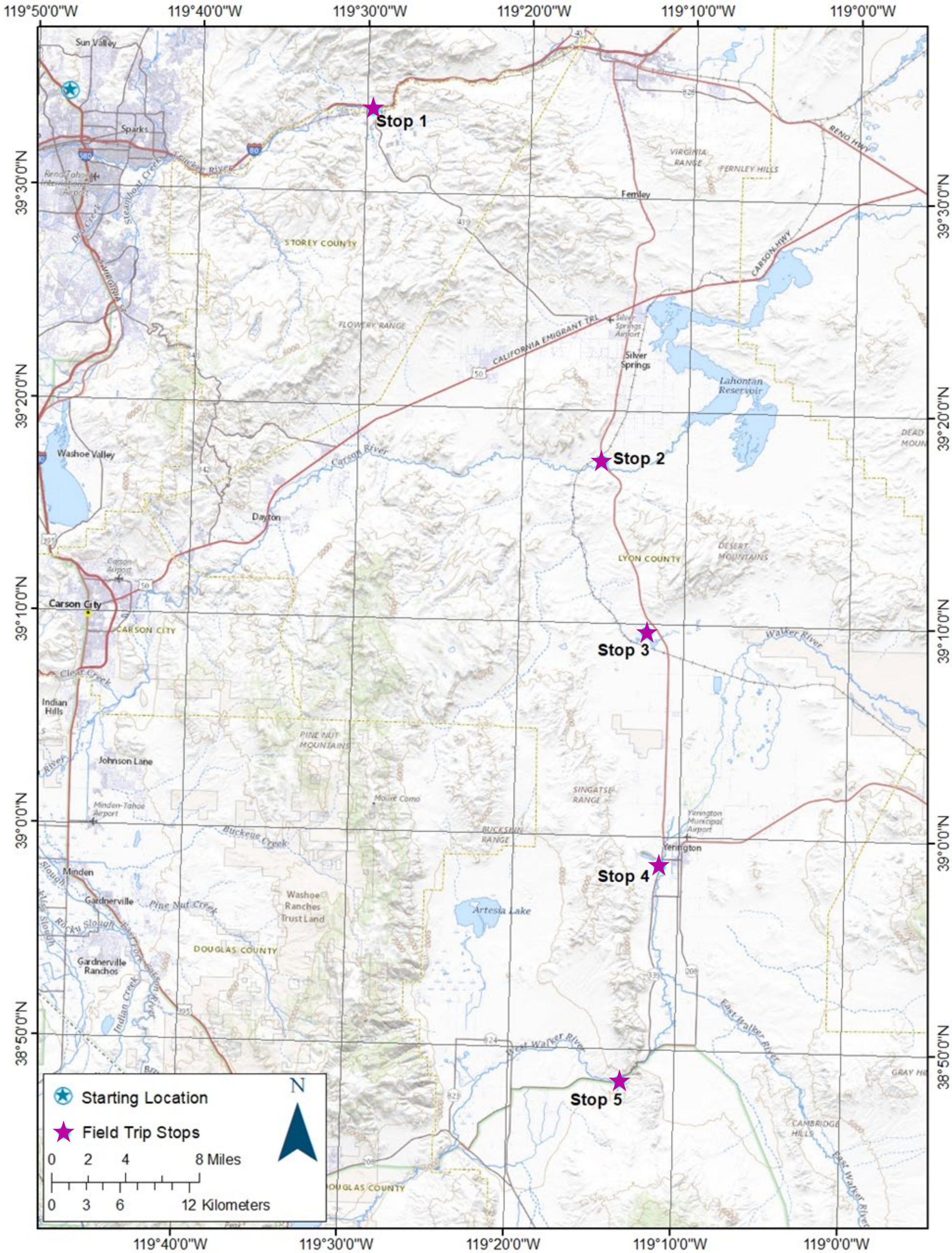


Figure 1. Overview map of starting location and field trip stops.

Approximate schedule

8:00 am – Meet at the Gold Building
8:30 am – Depart from the Gold Building parking lot
8:50 am – **Stop 1:** 102 Ranch Trailhead—Truckee River and Tahoe-Pyramid Trail
10:00 am – Depart 102 Ranch Trailhead
10:45 am – **Stop 2:** Buckland Station and Carson River
12:15 pm – Depart Carson River
12:30 pm – **Stop 3:** Mason Valley Copper Smelter and Wabuska Geothermal
1:30 pm – Depart Thompson Smelter
1:50 pm – **Stop 4:** Yerington Mine
2:50 pm – Depart Yerington Mine
3:05 pm – **Stop 5:** Wilson Canyon—west fork of the Walker River
Return to Reno at your own pace via preferred route (finish loop through Carson City or backtrack through Yerington) or follow the caravan back.

Road Log and Field Trip Stops

Start of trip is the Gold Building (GPS coordinate: 39.57175604°, -119.802847°; WGS 84)

39.57175604°, -119.802847° (0.0 miles) – Turn right onto Raggio Parkway, then turn left onto Dandini Boulevard. At 0.5 miles, turn left onto US Highway-395 south.

39.540352°N, -119.788106°W (3.3 miles) – Take Exit 68 and merge onto Interstate 80 East.

39.530850°N, -119.733218°W (7.1 miles) – Passing the Sparks Marina on the left (north of Interstate 80). The marina was formerly known as the Helms gravel pit, a quarry that provided rock for nearby construction and road projects starting in 1968. During the "New Year's flood" of 1997, it was inundated with floodwaters from the Truckee River. It was then developed into a public marina and swimming hole.

39.525415°N, -119.697594°W (8.8 miles) – Crossing the Vista fault, a normal fault, which bounds the east side of the Truckee Meadows.

39.524598°N, -119.694415°W (9.2 miles) – Entering the Truckee River canyon. The river has exposed the bedrock geology here, as it erodes away parts of the Virginia and Pah Rah ranges.

39.510450°N, -119.655139°W (12 miles) – Passing Lockwood to the south. This community has historically been inundated by flooding along the Truckee River as a result of heavy rainstorms and melting of the Sierra Nevada snowpack. The most intense flooding is usually associated with 'rain-on-snow' events.

39.530238°N, -119.610288°W (12.7 miles) – The dark rocks along the ridges to the south are from the McClellan Peak basalt flows (~1.4 million years ago [Ma]).

39.547631°N, -119.586996°W (16 miles) – Most of the hills on the horizon are older volcanic rocks (~10 Ma+). We are also beginning to see white tuffaceous rocks along road cuts and cut banks of the Truckee River.

39.567981°N, -119.526410°W (17.3 miles) – Sediments associated with pluvial Lake Lahontan are seen on the north side of road, and power plants to the south, including the Frank A. Tracy Generating Station, which is a natural gas power plant. Also, to the right is the Nevada Gold Mines Western 102 power plant (figure 2). The Western 102 power plant has a capacity of 115 MWe (megawatts electrical), supplying power from natural gas fired generators and a 1 MWe solar facility. This power plant is utilized to offset power used by mines operated by Nevada Gold Mines elsewhere in Nevada. Extra power produced here has been used by NV Energy to provide additional power to the area during periods of high demand.

39.567106°N, -119.498909°W (21.1 miles) – The white sediments in road cut south of the interstate are Lake Lahontan sediments.

Figure 2. Western 102 solar arrays can be seen here during a tour of the power plant in 2013. Photo by Rachel Micander.

STOP 1 39.566261°N, -119.492338°W (22.3 miles) Truckee River and the Tahoe-Pyramid Trail

Please park in the gravel parking lot. At this stop we will take a short walk to the river (~8-minute easy stroll, ~0.17 miles [.27 km]). Primarily Miocene volcanic rocks are visible on the hillsides to the north and south. The Miocene volcanic rocks are composed primarily of rhyodacite, dacite, andesite, and basaltic lavas and intrusive rocks (Rose, 1969; Schwartz and Faulds, 2004; Faulds et al., 2008). Rocks along the riverbank include Cretaceous granitic clasts and Miocene basaltic and andesitic clasts sourced from the Sierra Nevada, Carson Range, and Peavine Peak to the west.

The Truckee River flows 106 miles (~170 km) from Lake Tahoe in the Sierra Nevada, through the Truckee Meadows in Reno, to its terminus at Pyramid Lake, NV. The river is a vital resource and supplies about 85% of the water used by consumers in the Reno–Sparks metropolitan area. During the early settlement of the region in the late 1800s and continuing to modern times, the river and its ecology was and still is impacted by ranching, dam construction, straightening and dredging (flood control), and wildlife habitat loss. Over the last several decades, conservation efforts have worked to restore the river to a more natural state, including planting native riparian vegetation, stabilizing banks, restoring wetlands on the floodplain terrace surfaces, and building fish passageways. In addition, fencing has been placed around young trees to protect them from beavers (look for these at Stop 1). Although there is still much work to be done, the restoration efforts have resulted in reduced channel widths, increased pool depths, and decreased water temperatures (essential for native Lahontan cutthroat trout). Today, the river supports healthy populations of fish, birds, and other wildlife, as well as vibrant populations of trees, shrubs, and wildflowers. Along with red willow trees and coyote willow shrubs, the Fremont cottonwood is one of the more common trees at this location. They are large, soft-wood trees that provide prime habitat for nesting birds, as well as lumber for beavers looking to build dams. Cottonwood stands along riparian corridors contain the highest densities of birds compared to other riparian tree species. They help to stabilize riverbanks and provide shade, keeping the riparian corridor cool on hot days. The Fremont cottonwood is a flood-dependent species that suffered huge declines in population due to damming along the Truckee River during the past century (Truckee River Guide, undated). Many smaller shrubs grow along the river corridor and include rabbitbrush that displays beautiful yellow blooms in the late summer and early fall, big sagebrush, wild rose, and desert peach, among others. Look closely at the brush and you may be able to spot a few rose hips! While many of the wildflower blooms have come and gone by autumn, imagine how many wildflowers might show up on a spring day. Milkweed, blue sailors, and wild roses are just a few of the many species that grow here. How many different species can you identify today?

The river is also home to a wide variety of fauna including many species of fish, birds, and other mammals. Some of the many bird species that can be seen here are bald eagles, great blue herons, ducks, and a plethora of songbirds. Desert cottontail rabbits, mule deer, beavers, and American mink all call this river corridor home. Mink are carnivores and will feed on birds and ducks, bird eggs, fish, frogs, and even snakes (Truckee River Guide, undated). The large amounts of birds and other wildlife along the banks of the Truckee River make for perfect hunting grounds for the American mink. Take a minute to watch and listen to the sounds of the river—who do you see?

The Tahoe-Pyramid Trail (TPT) (mostly completed) extends along nearly the entire length of the river and provides a unique cultural link for the public to absorb the past and present environment of the river. Hikers, bicyclists, anglers, birders, and other recreationists will enjoy the trails unparalleled access (including Stop 1). We encourage you to take advantage of the many river access points along the TPT.

Modern hydrologic processes along the Truckee River are controlled by brief high-intensity rainfall events and melting of the winter Sierra snowpack from the river's 2,700 square miles (~7,050 km^2) drainage basin. The largest floods (>10,000 cfs [cubic feet per second]) within the last 150 years on the Truckee River occurred in 1907, 1928, 1937, 1950, 1963, 1964, 1986, 1997, and 2005 (Adams, 2012). A similar flooding event occurred in January 2017 and caused the submergence of many low-lying areas in the Truckee Meadows, including parts of downtown Reno and the industrial area of Sparks. Additionally, over 413 homes were evacuated due to failure of several drainage ditches in Reno. This event, and some of the historic floods, were related to 'rain-on-snow events' during strong atmospheric rivers (intense bands of Pacific tropical moisture).

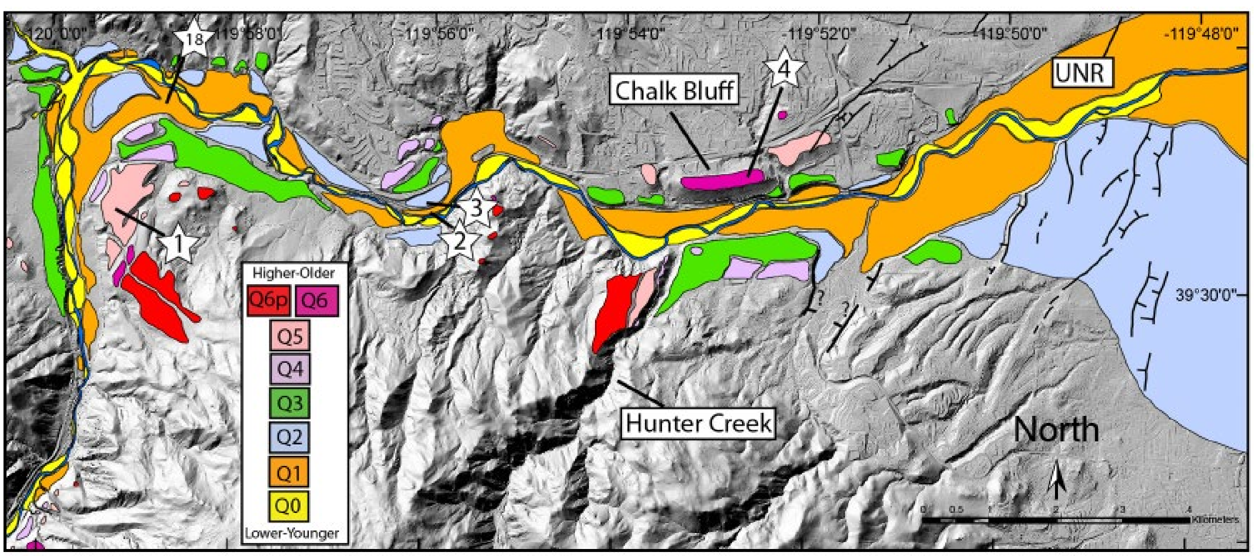


Figure 3. Map of abandoned Quaternary fluvial terraces and alluvial-fan pediments in the Verdi area west of Reno. These surfaces are graded to past levels of the Truckee River and are preserved due to river downcutting. Colors indicate relative age from yellow (youngest) and to red/purple (oldest). From Wesnousky and Owen (2020).

Throughout the length of the Truckee River, preservation of various terrace surfaces record evidence of fluvial deposition and incision related to Pleistocene glaciations, Sierra Nevada uplift, and lake level fluctuations of both pluvial Lake Lahontan and modern Pyramid Lake. In the upper reaches of the river near the town of Truckee, CA, Birkeland (1963, 1964) documented glacial outwash terraces correlated to the Donner Lake, Tahoe, and Tioga glaciations. Although the age of the Donner Lake glaciation is unknown, terrestrial cosmogenic surface exposure dating of glacial moraines at Lake Tahoe indicate that the age of the Tahoe and Tioga glaciations, around 120,000 years and 22,000 years respectively (Pierce et al., 2017), is similar in age to the glacial outwash terraces identified by Birkeland (1963, 1964).

Farther downstream in the area between Reno and Verdi, terraces along the Truckee River were originally described by Birkeland (1968a, 1968b). This original work was later refined through mapping by Ramelli et al. (2011), Wesnousky and Owen (2020), and Faulds et al. (in prep.), who identified at least six preserved terrace levels (figure 3). Terraces in this area are strath terraces (flat surfaces cut across bedrock with thin fluvial deposits) cut into the Hunter Creek formation and older units. The terrace surfaces have granitic boulders up to ~40 feet (12 meters) in diameter consistent with glacial outburst flooding, which has sufficient stream power to transport boulders of this size. Glacial outburst floods occurred when glacial ice advanced across the channel of the Truckee River causing temporary damming and eventual catastrophic collapse of the ice front, resulting in massive floods down the Truckee River drainage. Wesnousky and Owen (2020) proposed a model in which terrace deposits were originally continuous across the valley but became abandoned and preserved in the landscape due to incision related to uplift of the Sierra Nevada and subsidence of the Reno basin (i.e., Truckee Meadows) across east-dipping range-bounding normal faults.

Downstream of Reno, in the area of Stop 1, several different levels of fluvial terraces are preserved. Although glacial outburst floods certainly contributed to the development of terraces in this area, base level changes related to the highstand of pluvial Lake Lahontan (~15,000 years ago) and historic fluctuations of modern Pyramid Lake also influenced the terrace geomorphology. During the highstand of pluvial Lake Lahontan, sediment from the Truckee River was deposited as a large delta in the lake. Base level fall related to the drying and eventual desiccation of the lake resulted in incision through these deposits, which can be observed along the I-80 corridor. For more information about these sediments that the Truckee River has incised east of Stop 1, participants are encouraged to refer to NBMG's Earth Science Week field trip guidebook from 2016, *A River Runs Through It* (Koehler et al., 2016).

Geomorphic processes along the lower Truckee River are controlled by aggradation and degradation processes as the lake rises and falls through time. Over the last 120 years, the level of Pyramid Lake has lowered >66 feet (>20 meters) resulting in a suite of cut terraces along the Truckee River that extend 9.3 miles (~15 km) upstream to a point where bedrock in the channel inhibits incision (Adams, 2012). Adams (2012) mapped the evolution of terrace formation using rectified aerial photographs from multiple years and high-resolution topographic data (lidar) and determined that the channel has become steeper and straighter through time (figure 4).

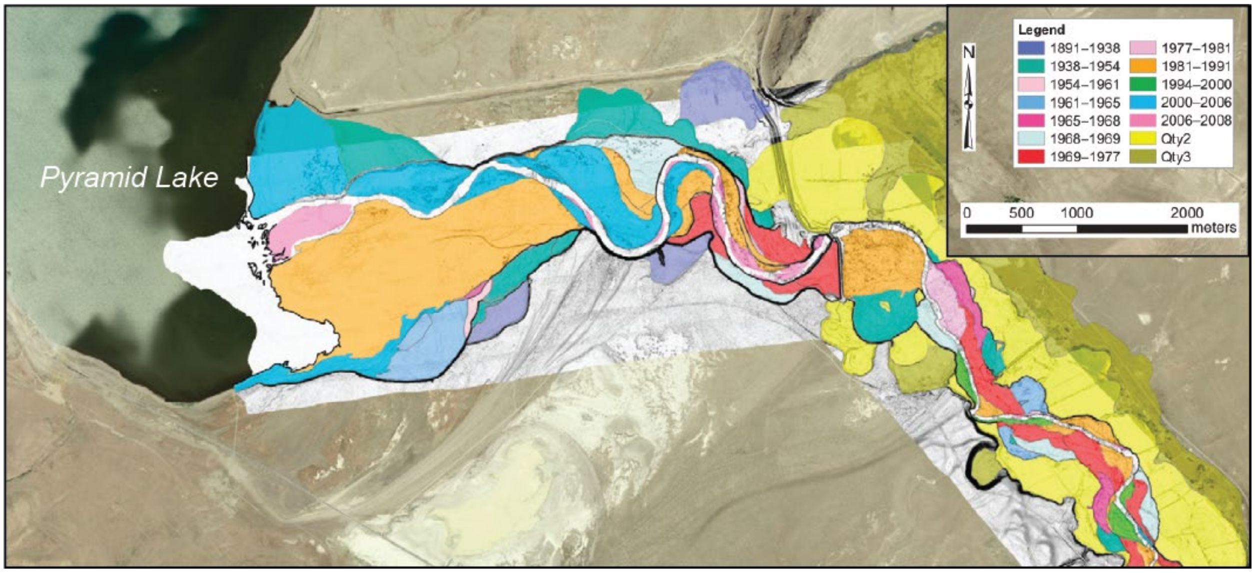


Figure 4. Geomorphic map of the lower Truckee River, where it enters Pyramid Lake, showing the distribution of fluvial terraces and the age of their formation. Modified from Adams (2012).

9.564281°N, -119.484650°W (22.9 miles) – Passing the Clark Plant on the left, a diatomite processing plant operated by U.S. Silica and utilizing diatomite obtained from nearby mines. Here, U.S. Silica produces diatomaceous earth, also known as DE or Kieselguhr. Diatomite is a sedimentary rock formed from microscopic critters called diatoms (figure 5). These diatoms lived in calm, freshwater environments. When the diatoms died, their silica shells accumulated over time forming thick layers of the white rock we see in places along the Truckee River corridor today. Diatoms have complex natural structures and are highly porous (~85% air) with high surface area. They are composed of nearly pure silica making diatomite very inert and ideal for a wide variety of applications. DE is commonly used in industrial products such as additives, paint and coatings, oil absorbents, biofuels, petro-chemicals, and pharmaceuticals. Diatomaceous earth is also used in some key agricultural and household products such as soil amendment, insecticide, kitty litter, feed additive, and as a drying agent.

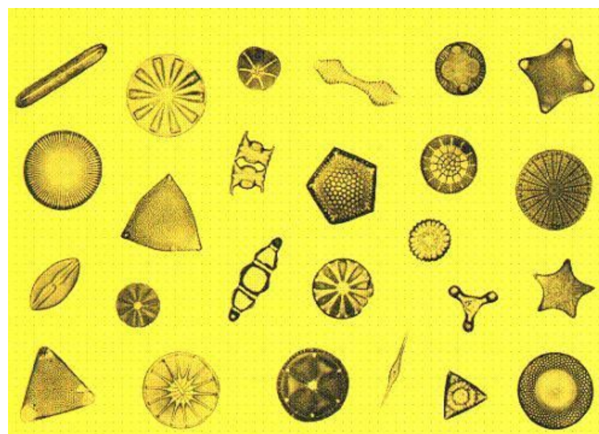


Figure 5. Diatoms. Photomicrographs courtesy of E. W. Harris. NBMG Postcard (https://pubs.nbmg.unr.edu/Diatomite-postcard-p/pc003.htm).

39.556784°N, -119.490312°W (23.4 miles) – Optional restroom break. If you choose to stop at one of the gas stations here, please meet the rest of the group at Stop 2 (Orchard Day Use Area across the highway from Buckland Station).

39.540124°N, -119.486558°W (24.6 miles) – Passing some outcrops of basalt, andesite, and dacite flows. These flows are Miocene in age (Faulds et al., 2008). Keep your eyes peeled for wild horses in this area as well!

39.524340°N, -119.477173°W (26.0 miles) – We are beginning to climb out of the Truckee River canyon and into the Virginia Range. The Virginia Range is an east- to northeast-trending range that is bounded to the north by the Truckee River canyon and to the south by the Carson River. Oldest rocks exposed in the Virginia Range are Mesozoic-aged metamorphosed sedimentary and volcanic deposits. These deposits were folded and regionally metamorphosed before granite plutons of late Mesozoic age intruded the area. Thick deposits of volcanic and sedimentary rocks overlie the

Mesozoic rocks. These volcanic and sedimentary deposits range in age from Oligocene to Pleistocene (Bonham and Papke, 1969).

39.492650°N, -119.410802°W (31.1 miles) – As we wind up the road, we start to see some pinyon pines dotting the hillsides. These are single-leaf pinyons (*Pinus monophylla*) found predominantly south of Interstate 80 in Nevada and are commonly intergrown with junipers. The single-leaf pinyon is also found in parts of Utah, Colorado, California, Arizona, and Baja California. In Nevada and Utah, there are ~20 million acres of pinyon-juniper forests. Pinyons are long-lived trees; about half of the pinyons in Nevada and Utah are estimated to be between 40 and 120 years old with ~9% of pinyons in Nevada over 200 years old (Zouhar, 2001).

We've been driving through some younger alluvial deposits and older gravel deposits (Quaternary) for the past few minutes. As we continue up the road, we start to see some different igneous rocks that are part of the ancestral Cascade arc (Cousens et al., 2008)—a series of volcanic and plutonic rocks that are generally Miocene to Pliocene in age. These rocks are regionally extensive and also crop out near Reno. What we see along the road here are lava flows and breccias that have been altered in some places by interaction with hot (hydrothermal) fluids.

39.486774°N, -119.400786°W (31.7 miles) – Beautiful road cut. Faulted volcanic and volcaniclastic deposits (figure 6). These deposits are middle to late Miocene in age and probably formed on the flanks of stratovolcanoes, which were part of the ancestral Cascade arc (Cousens et al., 2008). They were mapped in detail directly east of here in the Fernley West quadrangle (Faulds et al., 2008). The strata were tilted moderately by late Miocene regional extension (mostly ~13 to 9 million years ago) and then subsequently rotated significantly clockwise, as dextral shear associated with the Walker Lane migrated northward into the area ~5 million years ago (Faulds and Henry, 2008). The Walker Lane is a belt of strike-slip faulting in western Nevada and eastern California that accommodates ~20% of the right-lateral motion between the North American and Pacific plates (Faulds and Henry, 2008). As fault blocks were rotated clockwise, early northerly striking normal faults were rotated to easterly strikes and evolved into left-lateral faults as a means of accommodating the clockwise rotation. Thus, most of the faults in this area have a complex kinematic history.

Figure 6. Photos of faulted volcanic and volcaniclastic deposits along USA Parkway. Faults indicated by black arrows. Photos by Rich Koehler.

39.477972°N, -119.400636°W (32.4 miles) – Crossing into the Carson River watershed (from the Truckee River watershed).

39.464527°N, -119.382460°W (33.7 miles) – We are passing through the Ramsey mining district. Gold and silver were mined in this district. The metals are present in altered Tertiary rhyolite and andesite volcanic rocks that have been rotated significantly clockwise. Silicified fracture zones in these volcanic rocks contained the ore (Moore, 1969).

39.431673°N, -119.339473°W (37.2 miles) – Descending into Churchill Valley and Stockton Flat, home to Silver Springs and Lahontan Reservoir. Henry et al. (2007) produced a detailed geologic map of this area.

39.392555°N, -119.229323°W (41.0 miles) – Passing Lahontan Reservoir and the Dead Camel Mountains to the left. The Dead Camel Mountains were named for one of the camels that carried salt to the mines on the Comstock after it was found dead there. Salt was mined on many lakebeds and playas throughout the state and shipped to areas where silver and gold mining and processing was taking place. Mill operators believed that the addition of salt to a slurry of ground ore, water, mercury, copper sulfate, or sulfuric acid, helped precipitate the silver and gold (Rigby, 1999). You can read more about the salt that was used in the milling process on the Comstock in the virtual field trip *Exploring the Hot Springs Mountains* (Micander and Faulds, 2020).

39.322851°N, -119.246182°W (46.3 miles) – To the right is Churchill Butte, a lone mountain situated between Highway 50 and the Carson River. An area of Triassic to Jurassic metasedimentary rock is intruded by Cretaceous granitic rocks and can be seen on the eastern side of the butte. Warped and faulted west-dipping andesite and basaltic rocks cap the metasedimentary and granitic rocks. The west-dipping volcanic rocks and abundance of Mesozoic rocks on the eastern side of the butte suggest that Churchill Butte is the exposed part of a west-tilted fault block (Moore, 1969). Andesite and basalt boulders can be seen eroding from the lower elevations of Churchill Butte along Highway 95.

STOP 2 39.294860°N, -119.252608°W (48.5 miles) Buckland Station and Carson River

At this stop, we will take a short walk to the Carson River, discuss the geographic extent and character of the river and its role in modern agriculture, learn about the history of Fort Churchill and Buckland Station, and enjoy our picnic lunches. If we are lucky, a State Park representative will provide a historical perspective of the importance of this site. Restrooms are available at this location (pit toilets).

The Carson River starts its life high up in the Sierra Nevada as the East and West forks of the Carson River. The two forks come together in Carson Valley near Genoa and then continue to meander to the northeast before being dammed at Lahontan Reservoir. The river eventually drains through the Lahontan Valley and into the Carson Sink, supporting both agriculture and various populations of wildlife. The Carson River basin covers approximately 3,900 mi^2 (6,300 km^2) and extends roughly 180 miles (~290 km) from start to finish. It winds its way through Alpine County (CA), Douglas, Carson City, Lyon, and Churchill counties (NV).

Figure 7. Standing in the Carson River channel at Buckland Station, looking west. Flows are minimal to non-existent here following a dry water year. The lack of water gives geologists the opportunity to see sand bars, sediments in deeper channels, and other geologic features along the river channel that would normally be underwater. Photo by Rachel Micander.

The Carson River here is very different from what we observed at our first stop along the Truckee River (figure 7). The river at this time is quite dry after the long, hot summer that followed a below-average winter season (2020/2021). The Carson River is also fed primarily by snowmelt, whereas the Truckee River has Lake Tahoe and the surrounding watersheds as its source.

The river gradient is much flatter along the Carson River for a long distance of time opposed to the steeper grade of the Truckee River. As a result, the Carson River does not transfer large boulders as far as the Truckee River. At this location, paired terraces that have been incised by the river can be observed. These are formed as a result of the tectonic forces in the area—the Carson Sink is dropping down relative to the ground we are standing on. This gives the river power to drop down and incise banks rather than filling the entire basin with alluvium.

During the mid- to late 1800s, pioneers fished the river for native Lahontan cutthroat trout (Nevada's state fish), but historic mining activities, farming, overfishing, and the introduction of other fish species contributed to the demise of the cutthroat trout in the Carson River (Nevada Department of Wildlife, undated). Fishing occurs along the river today primarily between Mexican Dam (near Carson City) and Dayton, as river access is tricky due to private land and access restrictions. Some fishing does occur upstream of where we are at Buckland Station, but it is dependent on flow rates and water conditions. The river as a whole is in poor shape this year (2021) following extensive fires in the western reaches of the watershed and extreme drought conditions. While it is hard to imagine now, this river has experienced extreme flood events. During the 1997 "New Year's floods", a serious and extensive flood occurred along the Carson River, as well as the Walker and Truckee rivers. Flows along the Carson River near Fort Churchill were recorded at 22,300 cfs (Thomas and Williams, 1997). A typical range in flow along this location of the Carson River can be over 1000 cfs during spring flows and snowmelt events, but drops to between 50 and 150 cfs in the summer months, and then to near zero late in the season.

In addition to low flows and warm waters, the Nevada State Health Division has also issued an advisory that recommends fish caught from Dayton downstream to Lahontan Reservoir should not be consumed due to elevated methylmercury levels in the Carson River. These elevated levels of mercury originate from historic mining and milling practices that took place in the Comstock and Leviathan mines in the surrounding watershed. To learn more about the work that is going on to mitigate the mercury contamination in the Carson River, visit the Nevada Division of Environmental Protection (NDEP) website: https://ndep.nv.gov/environmental-cleanup/superfund. Currently, the NDEP oversees two Superfund sites on the National Priorities List. Those are the Carson River Mercury Superfund Site and the Leviathan Mine Superfund Site; more information is available for both of these sites from NDEP and the EPA.

39.269730°N, -119.235193°W (50.5 miles) – Climbing out of Churchill Valley into the Desert Mountains. This east-trending range separates Churchill Valley and the Carson River to the north from Mason Valley and the Walker River to the south. The Desert Mountains are typical of this area, where dextral shear associated with the Walker Lane has induced significant clockwise rotation of fault blocks (Faulds and Henry, 2008). However, this orientation differs from the common northerly trending ranges that characterize the Basin and Range Province and most of Nevada. The differently oriented fault blocks in this region were one of the first observations that led to recognition of the Walker Lane (Locke et al., 1940).

Along the highway are exposures of Quaternary alluvium and Tertiary sedimentary and volcanic rocks. Younger basaltic rocks cap some peaks here.

39.230805°N, -119.230002°W (53.4 miles) – Views of the Pine Nut Mountains to the west.

39.208295°N, -119.215616°W (55.2 miles) – Passing some more volcanic outcrops on the left side of the road (east).

39.183319°N, -119.210072°W (57.0 miles) – Entering the Walker River watershed (from the Carson River watershed).

39.167361°N, -119.198856°N (58.3) – In the hills to the right, eagle-eyed passengers may be able to spot some large culverts sticking out of the hillside. These culverts are at the mouth of abandoned mine features known as adits. Since these mines were abandoned, many bats have taken up residence in these old tunnels. There are bars inside the culverts that function to keep people from entering the mines and to preserve sensitive bat habitat.

STOP 3

39.161035°N, -119.203604°W (60 miles)
Mason Valley Copper Smelter and Wabuska Geothermal

High clearance vehicles are recommended for this stop.

The Mason Valley Copper Smelter

Figure 8. Town of Thompson and Mason Valley Copper Smelter during their heyday. Photo from the University of Nevada photo archives.

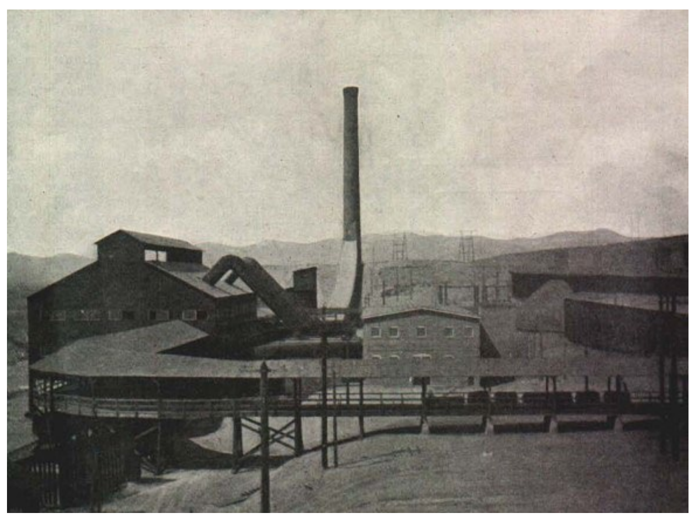


Figure 9. Mason Valley Smelter. From Read, 1912.

We are standing among the remains of the Mason Valley Copper Smelter (sometimes referred to as the Thompson Smelter, named for the co-owner William Boyce Thompson) and small town-site of Thompson, Nevada (figures 8 and 9). Construction of the smelter and small town began around 1910. A post office was in operation from June 28, 1911 through June 30, 1920 here as well. The Mason Valley Copper Smelter was built by the Mason Valley Mines Company following development of copper mines in Mason and Smith valleys. The town of Thompson and the Mason Valley Copper Smelter served as the northern terminus for the Nevada Copper Belt Railroad, which hauled copper ore from Ludwig in Smith Valley through Wilson Canyon and then headed north through Yerington and Wabuska. When the smelter began processing in ore in 1912, it was able to treat 700 to 1000 tons of copper each day. An article in the August 31, 1912 edition of Mining and Scientific Press noted that the "smelter is handling at present 750 to 800 tons of charge per day." Small amounts of gold and silver ore were also received and processed at the smelter. A small two-block town site that would later be named Thompson was built to house workers during this time. The town quickly grew after a second smelter was added to the site in 1913 or 1914. This second smelter was capable of processing an additional 500 tons of copper per day. The town grew to house ~350 residents and residential blocks, stores, saloons, and an auto repair shop were constructed to fill the needs of the booming population. Workers also lived in nearby Wabuska and Mason Valley. The smelter and town were short lived with the smelter closing for the first time in 1914. It reopened from 1917 through 1919, and then again from 1926 through 1928 (Nevada Expeditions, undated). The smelter was dismantled after it closed in 1928. All that remains today are foundations of old buildings and slag left over from the smelting process.

The site of the copper smelter was chosen after observing the prevailing wind direction for over a year. During this period of observation, the winds blew in the direction of the Carson Sink for ~90% of the time. For only 2% of the time, the winds blew in the direction of the agricultural districts of Mason Valley along the Walker River. However, according to records, this was almost unnecessary because the sulfur content of the ore was so low. The escaping smoke from the smelters carried very little SO_2 and arsenic was reportedly absent (Read, 1912).

Walking around the remains of the smelter and town, you will notice vast sheets of black material covering the ground in places. This is slag—a glass-like by-product that is leftover after the desired mineral (in this case copper) has been separated from the ore. The slag was then transferred to pots and emptied in the dump piles. The composition of the slag at this site is SO_2 (sulfur dioxide, 42%), FeO (iron oxide, 26.8%), CaO (calcium oxide, 22%), Al_2O_3 (aluminum oxide, 7.3%), MgO (magnesium oxide, 1%), and Cu (copper, .38%) (Read, 1912). Today, some copper ores are processed with heap leaching in Nevada. This is a process where crushed ore is piled up, and a solution is leached through the piles to dissolve the metals from the ores. In the case of copper, sulfuric acid is used. For gold, cyanide is used. For those chemists in the crowd, the sulfuric acid dissolves copper carbonate ores in the following reaction:

$$Cu_2CO_3(OH)_2(s) + 2H_2SO_4 \rightarrow 2CuSO_4 + H_2CO_3(aq) + 2H_2O$$

The resulting copper sulfate is soluble in water, so it can be readily processed. The carbonic acid (H_2CO_3) will probably break down to carbon dioxide and water: $H_2CO_3 \rightarrow H_2O + CO_2$.

As you walk around the site, notice the patterns in the slag (figure 10). How do you think these patterns were formed?

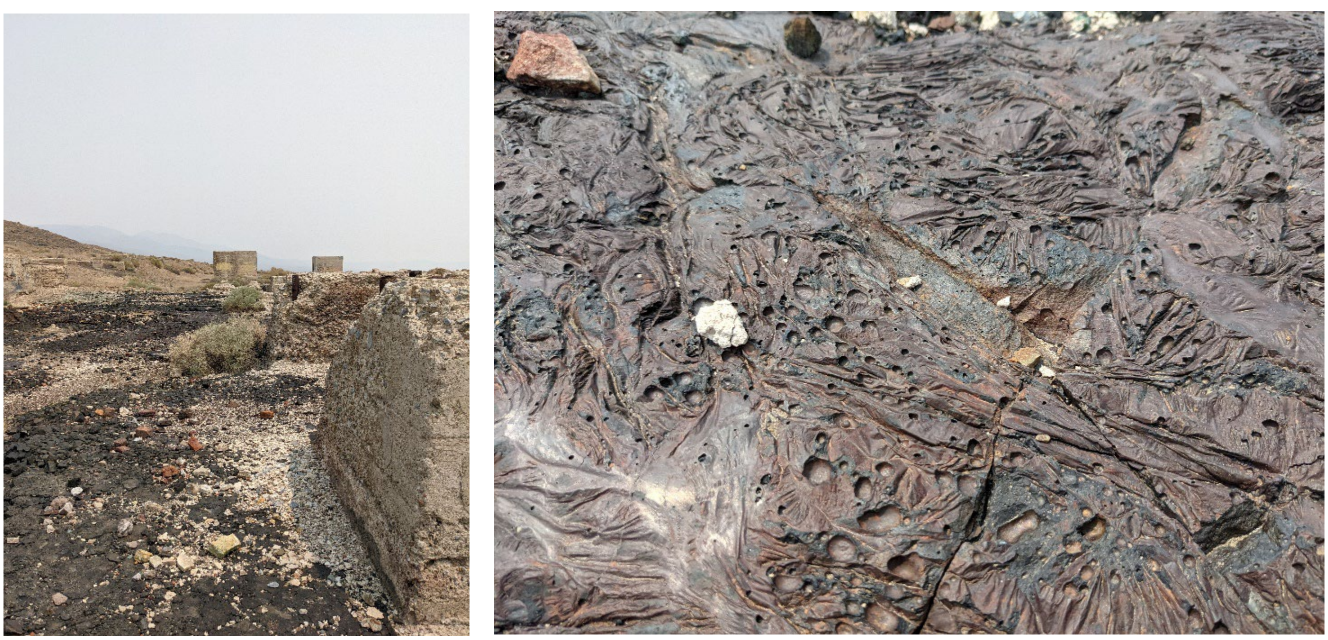


Figure 10. Slag piles among the remains at Thompson (left). Patterns seen in slag (right). Photos by Rachel Micander.

Wabuska (Open Mountain Energy)

Figure 11. Cooling towers of the recently installed Kaishan power system at the Wabuska geothermal plant, Lyon County. Photo by Bridget Ayling.

Wabuska is home to Nevada's longest-operating geothermal plant and also its smallest geothermal power plant. The Wabuska-I plant was commissioned in 1984 followed by the commissioning of the Wabuska-II plant in 1987. It has operated almost continuously since this time and currently generates approximately ~3.8 MWe gross electricity, which is enough to power ~3,000 homes. The plant utilizes near-boiling (208°F [98°C]) water that is pumped from two geothermal production wells onsite, with an average combined flow rate of ~4,596 gallons per minute (~290 liters/second). After passing through the heat exchangers, these production fluids are discharged at the surface about a mile (1.6 km) east of the plant and are not reinjected back into the subsurface. This is unusual for geothermal plants in Nevada: most operations reinject all production fluids into the ground to ensure that reservoir pressures and productivity are sustained. Despite this, the Wabuska geothermal system has apparently not experienced any production or thermal decline during its 35+ years of operation.

In early 2017, Open Mountain Energy (OME) acquired the Wabuska Geothermal Exploration Project from Homestretch Geothermal LLC. This acquisition included ~5,000 acres (~2,000 hectares) of private and federal geothermal leases, in addition to four geothermal production wells, wellfield piping and surface equipment, and permits and other rights associated with the operation of the power plant (Open Mountain Energy, 2017). In 2018, OME replaced the existing power plants at Wabuska with new Kaishan generators to improve the efficiency of the plant (figure 11). The Kaishan generators use the organic rankine cycle (ORC), which is a binary-cycle power plant technology. This means that a secondary working fluid is used to extract the heat from the geothermal fluid and spin a turbine. In the Kaishan plant, the working fluid used is R-245fa, which is a nonflammable refrigerant that boils at 59°F (15 °C). These binary-cycle units are more efficient at lower resource temperatures (such as those in the Wabuska geothermal system) compared to 'flash steam' geothermal plants, in which the geothermal fluid itself is 'flashed' to steam to spin the turbine. In 2020, Wabuska achieved a historic record in generation with the largest gross and net electricity generation ever reported (3.8 MWe and 2.3 MWe, respectively) due to the repowering of the plant with new Kaishan generators.

After no new drilling at the Wabuska geothermal field since 2017 (when the fifth production well PW-5 was drilled), OME drilled four new thermal gradient holes at the site in 2020: two of these are close to the existing wells and the surface plant (on private land), and the other two were drilled to the north, closer to the range front and on Bureau of Land Management (BLM) land. From April 2020 onwards, Wabuska (also known as Whitegrass-1) sells its power to the city of Glendale in California under a 25-year power purchase agreement (PPA) that was negotiated by the Southern California Public Power Authority (SCPPA).

The geothermal system at Wabuska has some unusual chemical characteristics: the geothermal fluids are sodium-sulfate brines ($Na\text{-}SO_4$), which are distinct compared to other geothermal plants in Nevada that are typically characterized by sodium-chloride and sodium-bicarbonate production fluids. The geothermal production wells at Wabuska produce fluid from relatively shallow depths (~300–400 ft [90–120 m]) from fluids hosted by Miocene basaltic andesite lavas. Temperature profiles collected in the wells suggest that the current production wells are producing from the outflow zone of the geothermal system (i.e., where the warm water is flowing out laterally). The location of the fluid upflow (i.e., where hot fluids are moving upward from deeper depths) is not well constrained. Several faults have been identified that may host upflow (see detailed geologic map of the area by Hinz et al., 2013), but these have yet to be drilled to test this hypothesis.

The Wabuska site was also formerly host to active hot springs that were reportedly used for bathing, medicinal purposes, and steam houses. These hot springs have not been observed at Wabuska since before the power plant was established. Prior to the commissioning of the geothermal plant, American Sodium Co. used evaporation ponds for sodium sulfate recovery (in the 1930s), Magma Power Co. drilled three wells at the site and identified a shallow permeable zone (at < 600 ft depth [183 m]) (in the 1950s), Agri-Technology Corp. built several greenhouses in the area using one of the wells previously drilled by Magma Power Co. at the site as a heat supply (in the 1970s), and Tad's Enterprises constructed an ethanol plant that also used one of these wells for heat (in the 1980s).

39.147715°N, -119.182743°W (61.7 miles) – Passing through Wabuska. Blink and you'll miss it!

39.109578°N, -119.180999°W (64.3 miles) – We are now driving through the fertile valley and farmlands of Mason Valley. Agriculture here is sustained by the water from the Walker River. Alfalfa and onions are a common crop here.

39.078472°N, -119.181307°W (66.3 miles) – Mason Butte to the left (east) are composed of Cretaceous granitic rocks and surrounded by younger alluvium.

39.049317°N, -119.183067°W (68.3 miles) – Passing the turn off to the Mason Valley Wildlife Management Area (MVWMA). The Walker River winds its way through the MVWMA providing water, food, and shelter for a wide variety of wildlife. Read more about the MVWMA and plan your visit with resources from NDOW: http://www.ndow.org/uploadedFiles/ndoworg/Content/Nevada_Wildlife/Mason%20Valley%20WMA%20%E2%80%93%20NV%20Brochure.pdf

39.014680°N, -119.182284°W (70.6 miles) – McLeod Hill to the east, onion fields, and tailings ponds to the west.

38.989146°N, -119.182871°W (72.4 miles) – Log Cabin Rest Area. Feel free to stop, if needed. Our next stop will be at the large open pit down the road (south) on the right.

STOP 4 38.978657°N, -119.185413°W (73.2 miles) Yerington Open-Pit Copper Mine

More than 65% of the world's copper is mined from deposits known as porphyry copper deposits. They are large deposits and typically contain 1 million tons to nearly a billion tons of ore. The grade of copper ore is typically about ~0.5–2 weight% copper. The Yerington open pit is a medium-sized example of one these deposits. During operations from 1952 to 1978, the Anaconda Mining Company produced 162.4 million tons of oxide and sulfide ore averaging 0.55 wt% copper. The Yerington mine was carefully studied for 10 years by geologists of the Anaconda Mining Company and professors and graduate students from Stanford University and the University of California at Berkeley. One of the keys of these studies was detailed systematic mapping of individual mine benches at a scale 1:600.

The ore is sourced from hydrothermal fluids exsolved from granite intrusions at depth. The granite forms bodies analogous to blisters on a rubber basketball, referred to as cupola zones. The magma migrates into these cupolas. Once in the cupolas, they exsolve very hot water (932–1112°F [500–600°C]) that causes the roof of the cupola to break. The result is magma and hot hydrothermal fluid enriched in copper escaping through the roof cupola. Decreasing pressure results in the hydrothermal fluid exsolving from the magma. The rising magma cools and forms planar dikes. The exsolved, rising, copper-enriched saline hydrothermal fluid keeps rising, and once it cools below 752°F (400°C), it begins to precipitate copper sulfide minerals such as chalcopyrite and bornite. The fluid also adds potassium to the wall rock, which results in precipitation of biotite and K-feldspar. The process is referred to as potassic alteration. As the hydrothermal system cools down to 572°F (~300˚C), it begins to form fine-grained muscovite, which is referred to as sericite by geologists. Copper sulfides continue to form, but not as much as what formed at depth. Pyrite, which is not a copper mineral, begins to form in addition to chalcopyrite. The Yerington porphyry copper deposit formed about 170 million years ago in the Jurassic Period based on uranium-lead (U-Pb) dating of the mineral zircon.

Zooming forward in time to the Oligocene Epoch, about 23 million years ago, widespread volcanism in the Yerington district resulted in the deposition of ash-flow tuffs, which resulted in a major unconformity between Jurassic rocks and Oligocene rocks. The Yerington deposits and the entire Yerington district is very distinct in that it experienced a significant amount of extension caused by normal faulting during the Miocene Epoch, starting around 14 million years ago. As the crust extended the normal faults rotated from ~60° dips to less than 30° dips. Most porphyry deposits are emplaced vertically into the country rocks and remain that way. In Yerington, though, they are tilted 90° to the west-northwest. Thus, if you observe the Yerington pit from the overlook, you are looking toward the deepest exposures of the deposit prior to extensional faulting and the shallowest exposures prior to extension are closest to the overlook. Due to this faulting, this is one of the rare opportunities for geologists to view both the bottom and top of a porphyry copper system in a relatively small area.

38.953504°N, -119.191365°W (75.3 miles) – Passing through the town of Mason.

38.940125°N, -119.192373°W (75.8 miles) – We are now driving along the Singatse Range, which extends north-south off to the right side (west) of the highway. The Singatse Range fault zone bounds the east side of the Singatse Range and is generally located along the base of the slope (range front) (figure 12). The fault zone is continuous from near Wilson Hot Spring in the south to west of Yerington in the north and becomes discontinuous to the north end of the range. As described in the U.S. Geological Survey (USGS) Quaternary Fault and Fold Database of the United States (Adams and Sawyer, 1999), the fault zone strikes north and is characterized by down-to-the-east normal displacement. This displacement has resulted in west-tilting of the mountain range (likely beginning in the Miocene), as well as west-tilting of Quaternary alluvium east of the fault in Mason Valley, which is ongoing today. The tilting has resulted in the Walker River flowing along the extreme west side of its Holocene floodplain in this area. Holocene and older Quaternary alluvium are juxtaposed against bedrock along the range front. Fault scarps (displacement of the land surface during earthquakes) have been noted across upper Pleistocene alluvium near Yerington and across late Pleistocene to Holocene fanglomerates southwest of Mason (Proffett, 1977; Dohrenwend, 1982).

38.924762°N, -119.194841°W (76.9 miles) – Walker River to the east of the highway.

38.899526°N, -119.188926°W (78.8 miles) – Note the volcanic rocks and gravels in the road cut on the right-hand side of the road. To the east is the confluence of the west and east forks of the Walker River.

38.877224°N, -119.191374°W (80.4 miles) – We are still driving along the range front of the Singatse Range. Note the steepness of the range, evidence of normal faulting, and triangular facets (figure 12).

Figure 12. Google Earth images of the Singatse Range fault zone. Map view on the left shows the prominent range front location of the fault noted by black arrows. The fault is sinuous and marks the contact between bedrock and alluvium. The street view image on the right shows triangular facets indicative of late Quaternary progressive offset across the fault.

38.830047°N, -119.192429°W (83.7 miles) – Entering Wilson Canyon along the west fork of the Walker River.

38.824130°N, -119.199895°W (84.3 miles) – Here, we see alluvial fans truncated by the river and some epic bedrock geology!

38.814200°N, -119.211994°W (85.3 miles) – Passing through some impressive volcanic cliffs.

STOP 5 38.809169°N, -119.220138°W (85.9 miles) Wilson Canyon

Please park in the parking lot. We will walk down to the Walker River from here. At this stop we will discuss the Walker River and its antecedent development across the mountain range, volcanic rocks exposed in the cliffs, as well as flora and fauna in the area, particularly the swallow nests in the canyon walls.

Similar to the Carson River, the Walker River begins as two forks—East and West—that come together south of Yerington in Mason Valley. Here at Wilson Canyon, we are standing along the banks of the west fork of the Walker River. The west fork originates in the high peaks (over 11,000 ft [3,400 m]!) to the west of Twin Lakes near Bridgeport, CA. It flows down through the Walker River canyon along US 395, past the towns of Walker, Coleville, and Wellington before cutting east through Wilson Canyon toward Mason Valley. Here, it joins the east fork of the Walker River and continues north through Mason Valley before heading back south through Walker River Paiute tribal land (home of the Agai Dicutta, which translates to "trout eaters") and eventually draining into Walker Lake. The river traverses through some incredible landscapes in Mono County (CA), and Douglas, Lyon, and Mineral counties (NV).

The Walker River extends from the crest of the Sierra Nevada to Walker Lake and has a drainage basin area of ~5,046 square miles (~8,120 km^2). The southern boundary of the Walker River drainage basin forms the northern border of Yosemite National Park. East of the Sierra Nevada range front, the river has a relatively flat gradient as it flows across basin-fill deposits. Over the last hundred years, water from the Walker River has been diverted for agricultural purposes, greatly diminishing flows along the lower reaches of the river and impacting lake levels in Walker Lake. Since 1882, lake level has fallen over 160 feet (~49 m) and has led to deep incision by the Walker River into the former lakebed. Stratigraphic studies and radiocarbon dating of sediments exposed by river incision (Adams, 2007) indicate that at least four lake highstands of Walker Lake have occurred since 3500 cal yr B.P. between elevations of 4,080 and 4,120 feet (1,245 and 1,255 m) (figure 13).

Wilson Canyon is a deeply incised valley along the west fork of the Walker River that cuts across the Singatse Range (figure 14). According to Steno's principle that "if a body or discontinuity cuts across a stratum, it must have formed after that stratum," the river course must have been established after the emplacement of the rocks of the Singatse Range. The high topographic relief of the Singatse Range and the presence of the Walker River canyon that cuts across it are consistent with active Quaternary uplift of the range and downdropping of Mason Valley across the Singatse Range fault zone. Thus, the river canyon may predate the uplift of the mountain range. Other alternative explanations for the origin of the canyon include headward erosion into the uplifted block and/or incision related to over-spilling from upstream lakes.

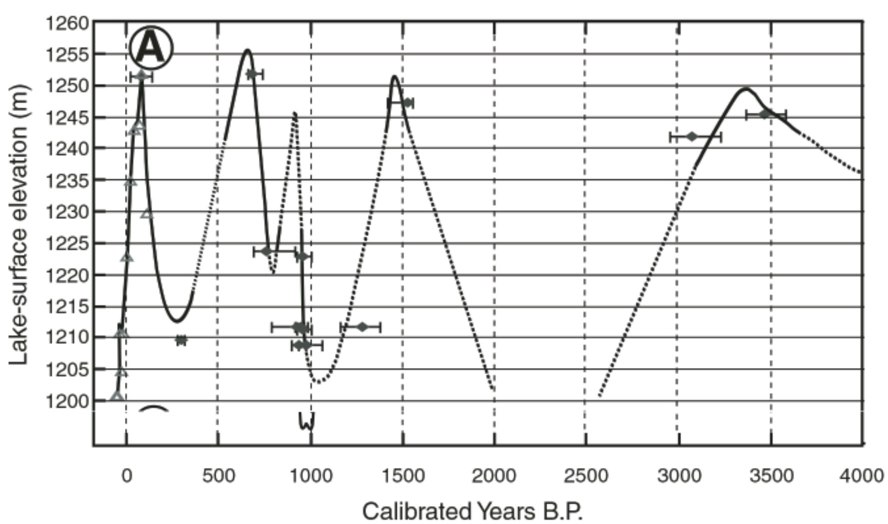


Figure 13. Lake level curve of Walker Lake showing at least four highstands in the last ~3,500 years. From Adams (2007).

Figure 14. The west fork of the Walker River cutting through Wilson Canyon (left). Rounded boulders are seen along the banks of the river (right). Photos by Rachel Micander.

Wilson Canyon dissects a thick section of volcanic rocks of Miocene age, ranging from approximately 15 to 8 million years old (Gilbert and Reynolds, 1973; Anderson et al., 2012). Volcanic rock types include andesite and dacite lavas, volcanic breccia, and rhyolite tuffs. These rocks are associated with the ancient volcanoes that formed part of the ancestral Cascades arc (e.g., Cousens et al., 2008).

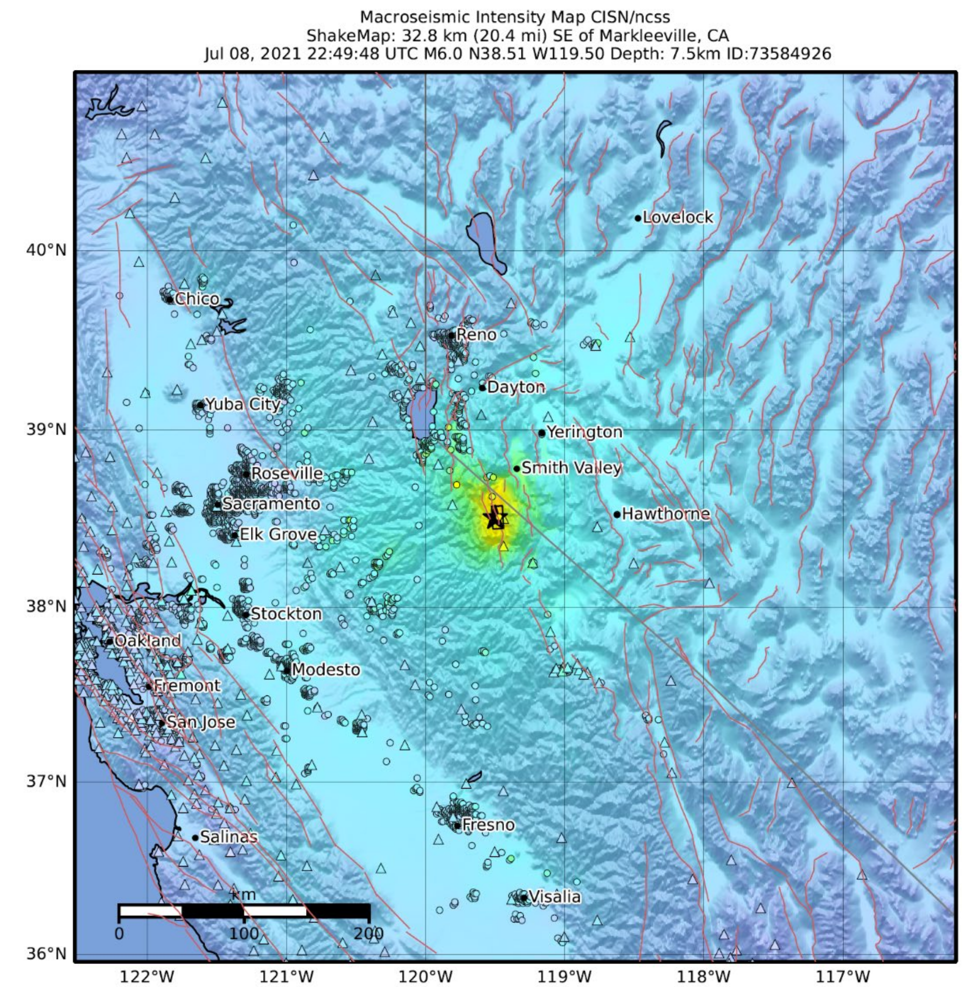
Wildlife here is similar to that along the Truckee River. The Walker River supports a healthy habitat of rainbow and brown trout (non-native), mountain whitefish, and bass. Lahontan cutthroat trout and mountain whitefish were the native species here. Historically, the Lahontan cutthroat trout migrated over 140 miles (~225 km) from Walker Lake to the headwaters of the east fork of the Walker River to spawn. However, lower water supplies, habitat degradation, and dams have prevented these fish from following their historical migration paths (Nevada Department of Wildlife, undated). The Walker River watershed has a wide variety of elevations and biomes allowing for high biodiversity. Cougars, black bears, foxes, mule deer, pronghorn, beavers, and mink can all be found around the Walker River. It is not uncommon to see bighorn sheep in the mountains around Walker Lake. Rabbits, ground squirrels, and other rodents are just a few of the smaller mammals that call this river home. Many species of birds also inhabit the region from songbirds such as the lazuli bunting and western tanager to raptors including bald eagles, hawks, and peregrine falcons. Walker Lake provides habitat for American white pelicans, common loons, and Clark's grebes. The canyon walls along the river at Wilson Canyon lend themselves to excellent habitat for cliff swallows. Look up toward the top of the cliffs and you will see a plethora of mud nests. These swallows generally leave their summer homes in the Great Basin by early fall to migrate to their wintering habitat in South America. In the summer months, these cliff swallows can be seen flying about catching insects and feeding their young.

Figure 15. Rose hips (left) and Hooker's evening primrose (right) along the west fork of the Walker River in Wilson Canyon. Photos by Rachel Micander.

The vegetation along the Walker River is also similar to that along the Truckee and Carson rivers (figure 15). Stands of cottonwoods, willows, and wild roses line the river banks in places. At higher altitudes, populations of pinyon and junipers are supported. Farther to the west toward the Sierra Nevada, yellow pines are commonly seen growing along the canyon walls. Sagebrush, rabbitbrush, and desert peach are some of the more common shrub species.

Two recent earthquakes have heightened awareness of seismic hazards in northern Nevada, including the M6.5 May 15, 2020 Monte Cristo earthquake and the M6.0 July 8, 2021 Antelope Valley earthquake. At this stop we will discuss these recent earthquakes in the context of their role in accommodating deformation in the Walker Lane tectonic province, the active tectonic belt that extends along the eastern side of the Sierra Nevada microplate.

The Antelope Valley earthquake occurred along the Slinkhard Valley fault at 3:49PM local time about 20.5 miles (33 km) southeast of Markleeville, CA near the town of Walker (figure 16). The earthquake was the result of normal faulting on a moderately dipping fault striking roughly north-south consistent with NW-SE oriented extension that is common in the Sierra Nevada. In addition to extension and normal faulting, the central Walker Lane is associated with northwest-striking right-lateral and northeast-striking left-lateral faults that are also capable of producing damaging earthquakes. Together the faults of the central Walker Lane accommodate approximately 20% (10 mm/yr) of the ~50 mm/yr of Pacific–North American plate relative shear.



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012) Version 10: Processed 2021-07-26T22:29:34Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture

Figure 16. Mercalli shaking intensity map of the Antelope Valley earthquake. Intensity is shown by color and corresponds to the index below map.

https://earthquake.usgs.gov/earthquakes/eventpage/nc73584926/shakemap/intensity

Shaking was widely felt in the Reno–Carson City urban corridor and as far away as San Francisco. Recorded Modified Mercalli Intensities (MMI) ranged from VI in the epicentral area to III–IV in the Reno area (figure 16). These values indicate that the motions were felt and frightened everyone close to the epicenter and felt quite noticeably by most people in Reno. Although damage was minimal, Highway 395 was closed in several locations due to extensive rockslides and boulder debris on the roadway.

Geologists with the Nevada Bureau of Mines and Geology quickly mobilized to the epicentral area to collect observations on the effects of the earthquake. The event provided a test run for NBMG's newly released 'Earthquake Clearinghouse' website (figure 17). The purpose of the earthquake clearinghouse website is to provide a virtual space to rapidly post observations and knowledge gathered from field investigations after major earthquakes to assist response and recovery efforts as well as to archive this data for the engineering and geologic scientific community working towards better understanding earthquake processes and reducing exposure to seismic risk. For the Antelope Valley earthquake, we archived GPS tracks, waypoints, and photographs from several different investigators (figure 18). In the event of a larger more significant earthquake, the website is designed to post news briefings and articles and to provide links to other agencies working on the event (e.g., Nevada Seismological Laboratory, U.S. Geological Survey, Earthquake Engineering Research Institute).

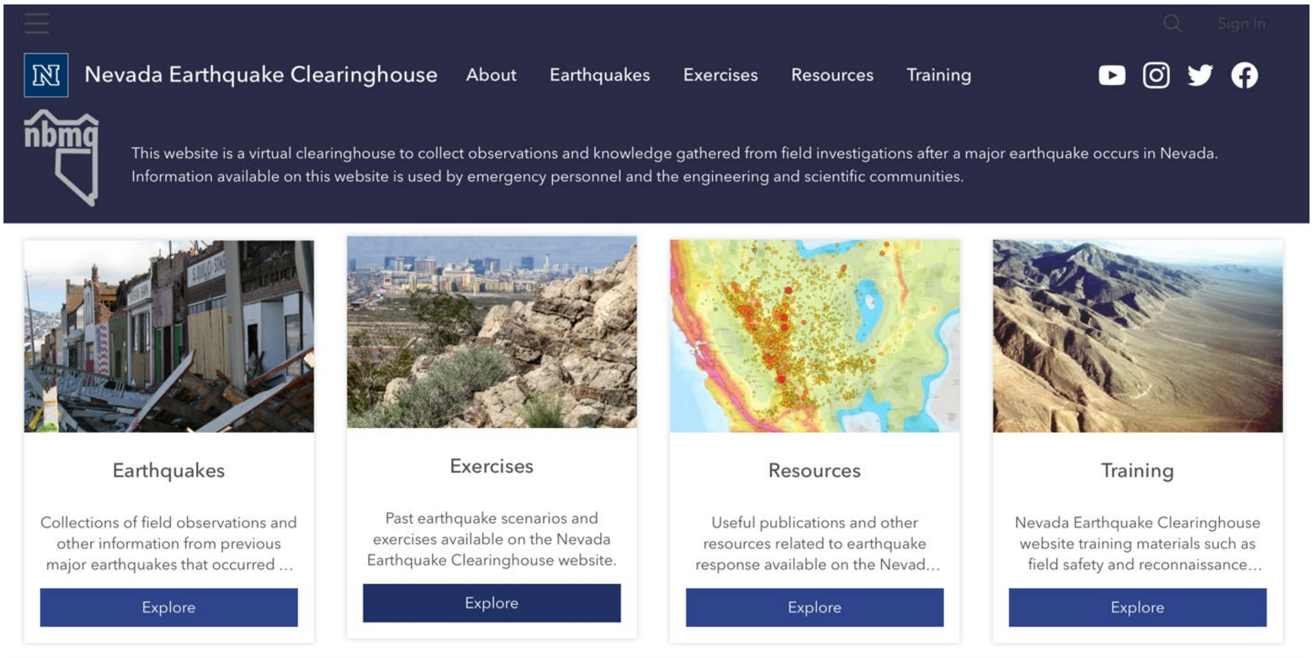


Figure 17. Homepage of the Nevada Earthquake Clearinghouse website (https://eqclearinghouse.nbmg.unr.edu/).

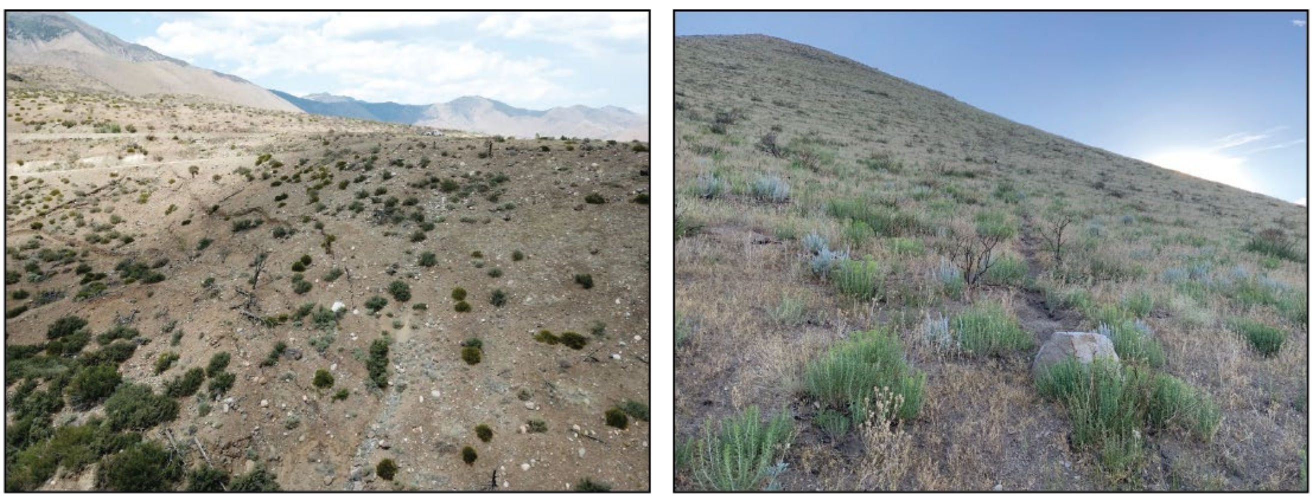


Figure 18. Photographs from the Antelope Valley earthquake archived on the Nevada Earthquake Clearinghouse website. Image on the left shows cracking along the slope due to slope settlement during shaking. Image on the right shows a large boulder and the track it left in the soil as it rolled down the slope. Left: Drone photo by Conni De Masi. Right: Photo by Seth Dee.

This concludes the guided portion of the field trip. Please feel free to return home via the route that best suits you. However, if you chose to continue the loop back through Carson Valley, there are a few extras in the road log.

38.808174°N, -119.229105°W – Wilson Canyon Rest Area – pit toilets and river access.

38.802047°N, -119.277219°W – Entering Smith Valley.

38.787904°N, -119.329532°W – Stay on Hwy 208. Veer right, past the church.

38.763205°N, -119.361854°W – The Pine Nut Mountains are ahead. The last large earthquake here was ~3,500 years ago, and fault scarps are visible in places along the range front. The Wellington Hills and Sweetwater Mountains are to the south.

38.752356°N, -119.370843°W – Bend right at Wellington.

38.757258°N, -119.378421°W – Passing through the town of Wellington. Nevada State Historic Marker No. 74 can be found in the town of Wellington. Feel free to stop and see for yourself or read on for the details from the historical marker:

> *"Following the mining boom in the Aurora District in 1860, Jack Wright and Leonard Hamilton put up a bridge across the West Walker River and established a stage station at this location. Wagons and stages were repaired, horses shod and the station became a trading center for nearby ranches and farms.*
>
> *In 1863, Daniel Wellington bought out the interests of Wright and Hamilton and the station became known as "Wellington's." The Wellington Hotel, located about a half mile south of the station, was constructed by wagonmaster Zadok Pierce in 1875. Over the years it has served as a livery stable, freight station, general store, and post office."*

38.760465°N, -119.383002°W – Crossing the west fork of the Walker River once more.

38.766705°N, -119.393328°W – The Smith Valley fault zone can be seen extending to the north of the highway along the range front that separates bedrock of the Pine Nut Mountains on the west from Quaternary alluvial fans in Smith Valley on the east (figure 19). To the south of this location, the fault extends along the range front of the Wellington Hills. The fault has an average strike of N10E and is characterized by triangular facets and over-steepened basal slopes indicative of long-term down-to-the-east normal displacement. This progressive deformation has resulted in over 5,900 feet (1,800 m) of vertical relief along the central part of the fault zone. Holocene and late Quaternary alluvial fans are

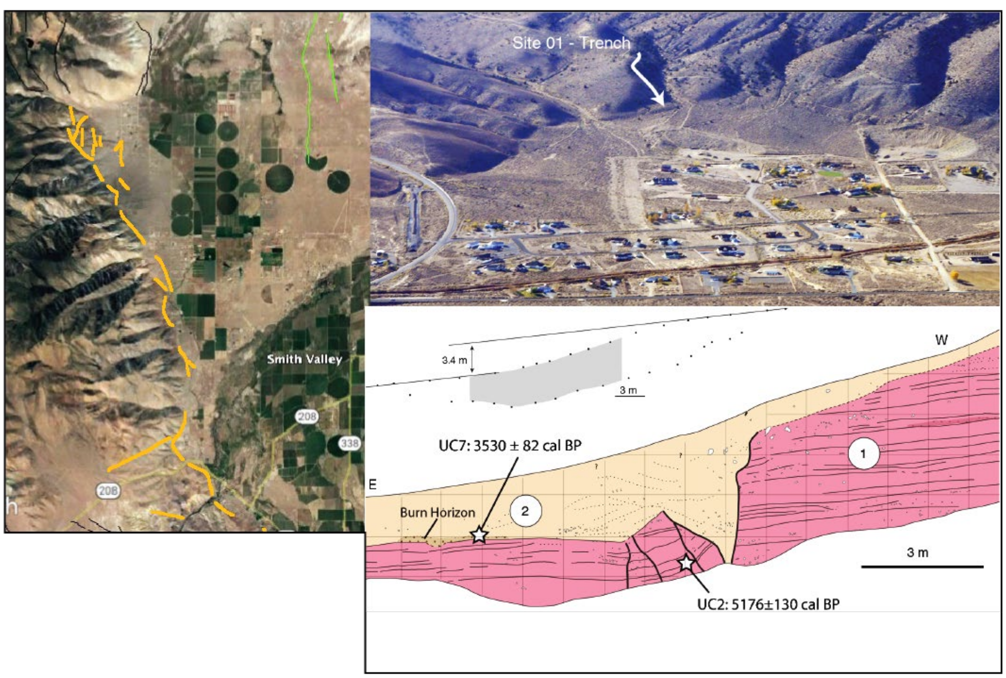


Figure 19. Image on the left shows the Smith Valley fault zone mapped by orange lines along the range front. Images on the right show the site of a paleoseismic trench investigation (Site 01) and the resulting trench log indicating the occurrence of at least one earthquake prior to about 3,500 years ago (Wesnousky and Caffee, 2011). Note the dark shadows along the range front that indicate the location of the fault.

cut by the fault as well as juxtaposed against bedrock in some areas. Wesnousky and Caffee (2011) investigated the paleoseismic history of the fault through trenching and geochronologic analyses of the ages of faulted deposits. They determined that the most recent earthquake occurred between ~5,100 and ~3,500 Cal. yr BP and that the fault has a late Quaternary slip rate of 0.1–0.3 mm/yr.

38.762720°N, -119.402881°W – We are now leaving Smith Valley through the divide between the Pine Nut Mountains (north) and the Wellington Hills (south).

38.759116°N, -119.424788°W – Crossing over Jack Wright Summit.

38.753694°N, -119.433705°W – We are passing through some common high desert biomes—pinyon and juniper forests, sage brush, and other desert shrubs. In the spring, wildflowers such as phlox and Nevada lupine can be found scattered amongst the scrub.

38.728154°N, -119.549753°W – Veer right onto Highway 395 north at Holbrook Junction. We are north of Topaz Lake and Antelope Valley, the location of the July 2021 earthquake (Antelope Valley) we discussed at Stop 5.

Figure 20. Tamarack Fire burn scar along Highway 395 in Douglas County, Nevada. Photo by Rachel Micander.

38.747896°N, -119.566622°W – Passing through the Tamarack Fire burn scar (figure 20). The Tamarack Fire was sparked by a lightning strike in a remote portion of the Mokelumne Wilderness in California on the afternoon of July 4th, 2021. The decision was made by the U.S. Forest Service to monitor the fire due to the remote location and lack of fuels surrounding the smoldering tree. However, on July 16th, the winds picked up and rapidly fueled the fire causing explosive growth. The fire burned more than 68,000 acres in California and Nevada and caused more than 8.7 million dollars in damage.

38.781947°N, -119.587958°W – Crossing back into the Carson River watershed.

38.809409°N, -119.611278°W – Simee Dimeh Summit. The name comes from a Washoe phrase that translates to "double water" or "double springs".

38.960629°N, -119.776942°W – The Genoa fault can be seen extending along the base of the Carson Range west of the highway. The Genoa fault is part of the Carson Range–Kings Canyon fault system and is one of the most active faults in the Basin and Range Province, posing a high seismic hazard to the Reno–Carson City urban corridor. The Carson Range and Carson Valley are fault blocks that may have split from the main Sierra Nevada block during the Plio-Quaternary, possibly in the past 2.5 to 3 Ma (Birkeland, 1963; Trexler et al., 2000; Henry and Perkins, 2001). More than 6,600 feet (2,000 m) of down-to-the-east normal throw across the fault is indicated near Genoa by 4,900 feet (1,500 m) of range-front relief and some 1,640 to 3,300 feet (500 to 1,000 m) of adjacent basin fill (Ramelli et al., 1999). Late Holocene scarps are evident along the entire length of the system (best seen in afternoon sunlight), and the fault is exposed in a quarry near Genoa (figure 21). The earthquake history of the fault has been investigated in numerous trenching studies (Ramelli et al., 1994, 1999; Ramelli and Bell, 2009). These studies indicate the occurrence of two earthquakes after about 1,740 years ago with the most recent event <390 years ago.

Figure 21. Image on the left shows the Genoa fault extending along the base of the Carson Range. The fault is highlighted by the dark shadow in late afternoon light. Image on the right shows the fault plane of the Genoa fault exposed in a quarry south of the town of Genoa, NV. Photos by Rich Koehler.

39.051502°N, -119.777996°W – Crossing the Carson River. Is there more water here than there was at Buckland Station? Think about why this could be.

39.082040°N, -119.775889°W – At this location the Indian Hill fault extends across the highway. The Indian Hill fault, Carson City fault, and Kings Canyon fault system splay to the north-northeast from the northern Genoa fault and represent a major discontinuity in the Carson Range fault system (which includes the Genoa fault). These faults pose a significant near-field seismic hazard to the Carson City area and have all generated earthquakes in the Holocene. Figure 22 shows where the Indian Hill fault crosses Highway 395. Early trenching investigations on the Indian Hill fault (Trexler and Bell, 1979) determined that the most recent earthquake occurred sometime in the last 3,000 years. Recent trenching studies directly east of the highway led by UNR graduate Ian Pierce have confirmed Holocene activity along the Indian Hill fault. Trenching along the Kings Canyon fault system by NBMG geologist Craig dePolo also identified several Holocene events (dePolo, 2014).

Figure 22. Indian Hill fault (orange line) where it crosses Highway 395, view to the north. The hills behind the fault are the result of normal displacement across the fault. Photo credit: Annotated image from google street view.

39.206508°N, -119.793444°W – Crossing into Washoe Valley from Eagle Valley. To the right (east) is a Quaternary cinder cone vent – this is the McClellan Peak volcanic vent. A quarry is also visible in the hills east of Washoe Lake. This operation is excavating cinder deposits from the McClellan Peak vent—a 1.4 Ma deposit. The cinders at the quarry are red in color due to oxidation and are used as a decorative stone (Dee et al., 2017). Read more about the volcanic rocks in this area, including some paleovalley lavas in the 2017 Earth Science Week Field Trip Guide (Dee at al., 2017).

39.232898°N, -119.811702°W – 39.232898°N, -119.811702°W – Washoe Valley fault on the left and Washoe Lake to the right (figure 23). The Washoe Valley fault is part of the Carson Range–Kings Canyon fault system and represents the northward continuation of the Genoa fault. To the north, the fault becomes the Mount Rose fault zone and extends into the Reno area. Trench excavations across the Washoe Valley fault by Ramelli and dePolo (1997) indicate the occurrence of two past faulting events in the last 1,700 years. Active research focused on comparing the earthquake histories along the entire Carson Range–Kings Canyon fault system (Genoa, Washoe Valley, and Mount Rose faults) will eventually shed light on the maximum rupture lengths and magnitudes of future potentially damaging earthquakes.

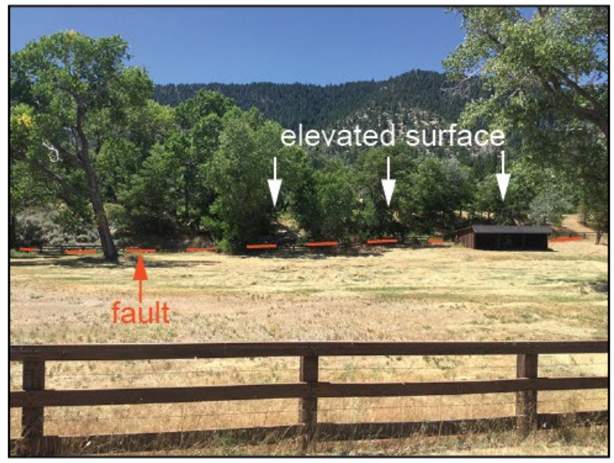


Figure 23. Image on the left shows Washoe Lake and the Carson Range. The Washoe Valley fault extends along the base of the range. Image on the right shows the Washoe Valley fault extending across the photo just behind the building. Note the elevated land surface behind the building, which sits on the down-dropped side of the fault. White arrow shows elevated surface and dashed red line shows fault. Photos by Rich Koehler.

39.294890°N, -119.823640°W – The appropriately named Slide Mountain is to the left (west) (figure 23). Slide Mountain has experienced a number of landslides and debris flows throughout time, the most recent being the Memorial Day 1983 landslide and resulting debris flow. New LiDAR data in this area show geologists that there have been past landslides here (figure 24). Figure 24 shows recent NBMG mapping of the landslides (Carlson et al., 2019). Some of the landslides are cut by the fault (older than faulting), and others bury the trace of the fault (younger than faulting). Future research on the age of the landslides holds potential to better constrain the slip rate of the fault. More information about the LiDAR data and a story map highlighting the LiDAR products can be viewed at the following website: https://nbmg.blog/2019/01/08/below-the-neon-renos-bare-earth-recent-reno-sparks-carson-city-lidar-acquisition-project/

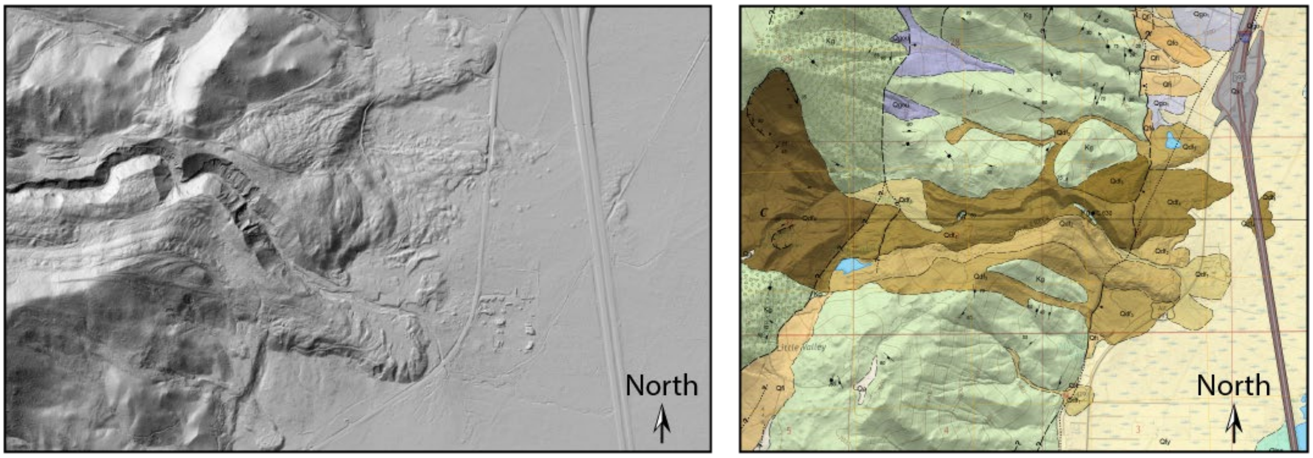


Figure 24. Image on the left shows a bare earth hillshade map generated from LiDAR data. Image on the right shows geologic mapping (Carlson et al., 2019) and highlights debris flow and landslide deposits (shades of brown).

39.390897°N, -119.759036°W – We are passing the Steamboat Hills Geothermal Plant, which began producing electricity in 1984. This area was once home to over 50 springs, boiling pools, fumaroles, and small geysers. These springs were frequented by the Washoe people who settled in the area (Ressel et al., 2019). For more information about Steamboat and the history here, check out the 2019 Earth Science Week Field Trip Guide (Ressel et al., 2019).

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