Guide for the Earth Science Week Field Trip, October 12, 2019

Nevada Bureau of Mines and Geology

Educational Series E-65

Lode and Behold! Geology and Natural Resources of the Truckee Meadows and Virginia City

The Combination Shaft, Virginia City

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2019

Logistics

The field trip will begin at the Galena Junction shopping center which can be accessed via the Mount Rose Highway (State Route 431). From downtown Reno, take I-580 south to exit 56. Stay right (west) and merge onto State Route 431. Take the first right into the Galena Junction shopping center–on the left is a Starbucks, and to the right is a McDonald's. From Carson City, take I-580 north to exit 56. Turn left (west) onto State Route 431 and make a right into the Galena Junction shopping center. We will meet in the parking lot between Raley's and Starbucks, closest to the Starbucks. Look for the Nevada Wolf Pack flag. The address is: **18250 Wedge Pkwy, Reno, NV 89511**.

Please plan to arrive by **8:00 am.** Following some introductory comments, route plans, and discussion, we will depart no later than **8:30 am**. There is plenty of parking at the Galena Junction shopping center and we encourage field trip participants to carpool and/or leave extra cars in the parking lot. Although all of the roads that we will be on are paved or gravel/dirt, there is limited space for parking. Restrooms are available on the northern end of Virginia City, across the street from stop 2 (at the Fourth Ward School), and at the Arizona Comstock Mill (stop 3).

Road Log mileage is cumulative and may vary depending on tire size and other factors and should be considered approximate. GPS coordinates are provided for each of the stop localities in the WGS 84 coordinate system. Note that the stops within the Ormat geothermal plant are not publicly accessible and **participants will not be able to tour this location on their own**. Please bring a pack lunch, water, sturdy shoes, jacket, hat and sunscreen, camera, and a smile.

Introduction

This year, Earth Science Week is celebrating the theme *Geoscience is for Everyone.* In conjunction with the theme, our field trip will take us on a tour of some of the geological sites in the southern portion of the Truckee Meadows and in and around Virginia City. We will discuss the geology related to geothermal energy production, current and historical mining and production, and natural hazards, which include volcanic activity, earthquakes, fires, flooding, and landslides. We will also learn about abandoned mines, hazards associated with old mining features, and native flora and fauna.

Our day begins with a tour of the Steamboat geothermal power plant operated by Ormat Technologies, Inc. We will learn about geothermal power generation, the science behind geothermal energy, and common features associated with the Steamboat area including hot springs, fumaroles, and geysers. We will also address the source of the hot water that drives the geothermal plant at Steamboat and other places in Nevada, making our state the second leading producer of geothermal energy in the United States.

Following our discussions at Steamboat, we will review the geologic and tectonic setting of the Truckee Meadows, the Carson Range, and the Virginia Range, breaking for lunch at 'Pine Basin' within the Steamboat geothermal area. After lunch we will travel to the Chollar Mine where we will discuss historic and modern mining on the Comstock, mineralization, faulting, and abandoned mines. Our last stop of the day will be at the Arizona Comstock Mill, where we will see how ore was treated after it was mined.

As we tour the Virginia City area, remember that 2019 is the 160th anniversary of the 1859 discovery of the Comstock Lode, one of the richest vein deposits of precious metals ever found (LaPointe and Price, 2009). This area is rich in mining history and culture—if it weren't for the geological processes that contributed to silver and gold deposition in this region millions of years ago, Virginia City and the Comstock would not exist.

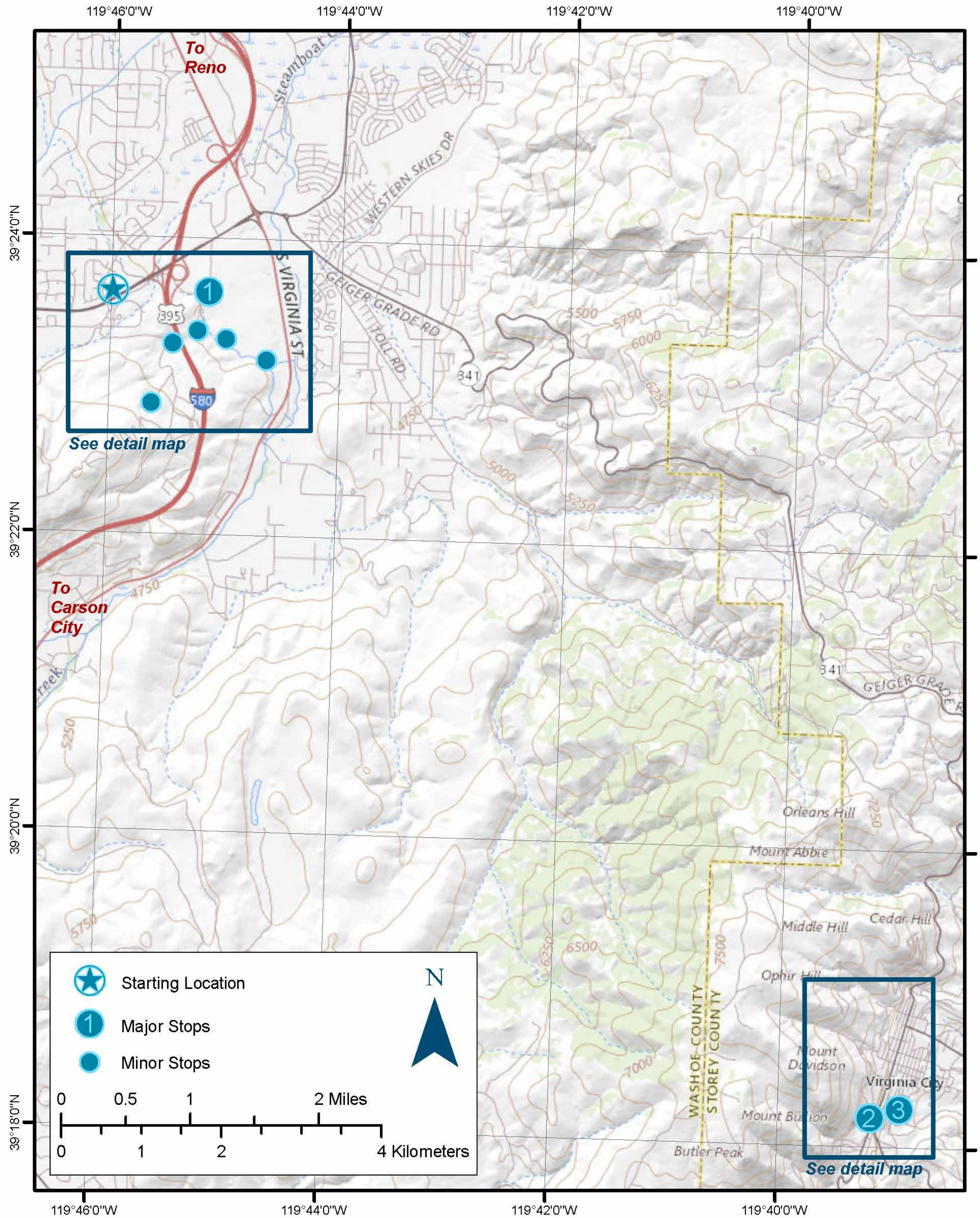

Figure 1. Overview map showing the starting point and locations that will be visited during this field trip. See figure 2 for detailed locations.

Approximate Schedule

8:00 am – Meet in the parking lot near Starbucks located at 18250 Wedge Parkway, Reno, NV 89511.
8:30 am – Depart.
8:40 am – Stop 1: Steamboat geothermal area (includes four internal stops to the modern and ancient hot spring sinter deposits, geyser locations, and the power generation plant). Our tour guide will be Ormat senior geologist, Matthew Sophy.
11:30 pm – Lunch at 'Pine Basin'.
12:30 pm – Depart Steamboat geothermal area.
12:30 – 1:00 pm – Restroom breaks en route to stop 2 as needed. Reconvene at stop 2 at 1:20 pm
1:20 pm – Stop 2: The Loring pit, Chollar raise, and Comstock fault. Mine and rock collecting location. Our guide for this part of the trip is Steve Russell, a geologist and long-time mineral explorationist on the Comstock.
2:20 pm – Depart from the Loring pit, Chollar raise, and Comstock fault.
2:30 pm – Stop 3: Arizona Comstock Mill.
3:30 pm – Return to the Galena Junction shopping center if picking up vehicles, or depart Virginia City at your own pace.

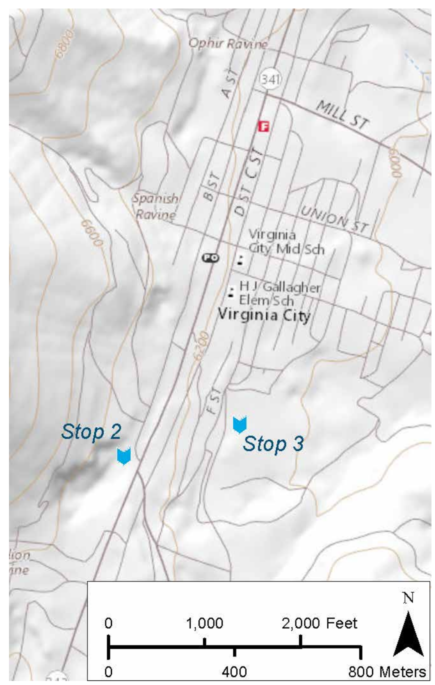

Figure 2. Detailed maps showing the locations of stop 1 and the internal stops at the Steamboat geothermal area (left) and stops 2 and 3 in Virginia City (right).

Road Log (see figures 1 and 2 above)

Start of trip is in the parking lot to the north of Starbucks at the Galena Junction shopping center:
18250 Wedge Pkwy, Reno, NV 89511 **(GPS coordinate: 39.393958°, -119.766412°; WGS 84).** Many of the notes in our road log are adapted from NBMG Special Publication 19: Geologic and Natural History Tours in the Reno Area by Tingley et al. (2005).

ZERO miles at intersection of Galena Junction shopping center and Wedge Parkway.

0.0 – Turn left (south) onto Wedge Parkway, then turn left (east) onto the Mount Rose Highway (State Route 431).

1.1 – Turn right (south) onto Power Plant Road, located immediately after the Tamarack Junction billboard. Proceed to the locked gate.

1.4 – **Stop 1 (GPS coordinate: 39.393997°, -119.752508°): Steamboat geothermal power plant** Roads inside the Steamboat Springs geothermal area are narrow and parking is limited. There is a parking lot just outside the gate, where we will consolidate into fewer vehicles. Stops within the geothermal area will include the lower sinter terrace and geyser mounds, the main plant, and the upper terrace, where we will be able to collect native sulfur, cinnabar, and chalcedony.

2.3 – **Stop 1A (GPS coordinate: 39.388710°, -119.749808°): Steamboat power plant and control center.**

3.8 – **Stop 1B (GPS coordinate: 39.386422°, -119.743909°): Main sinter terrace.**

4.1 – **Stop 1C (GPS coordinate: 39.389551°, -119.753992°): High terrace (silica hill) silica sinter.**

5.2 – **Stop 1D (GPS coordinate: 39.381354°, -119.760416°): Silica pit.**

6.0 – **Lunch (GPS coordinate: 39.388132°,-119.757477°): 'Pine Basin'** Following lunch, we will head back to the Ormat parking lot, then travel east on State Route 431 up Geiger Grade toward Virginia City and the Comstock.

6.6 – Collect vehicles at Ormat parking.

6.9 – Turn right (east) onto the Mount Rose Highway (State Route 431).

7.6 (0.0) – **Re-set trip odometers here.** Travel straight through the intersection and continue east onto Geiger Grade (State Route 341).

0.2 – Proceed through the roundabout, taking the first exit to stay on Geiger Grade Road. To the left at about 10:00 is a light colored rhyolite dome that is mined for aggregate.

0.7 – To the right is Toll Road. This is the route of the original Geiger-Tilton Toll road built in 1862 to connect Reno and Virginia City.

1.5 – Start climbing into the Virginia Range. At about 10:00 is a piñon pine-covered hill (above the houses) composed of granodiorite, a plutonic igneous rock. This outcrop of granodiorite is completely surrounded by younger volcanic rocks.

1.8 – Note the burned areas on the slopes ahead. Portions of this region were burned in 2004, 2005, and 2011. When sagebrush steppe ecosystems burn, they are often taken over by cheatgrass—an invasive and persistent species. If the area does not burn again in the foreseeable future, native shrubs will start to reestablish themselves and the ecosystem may return to a sagebrush community. The first perennial plant to return is usually rabbitbrush. The yellow flowering blue-gray shrubs you see in this area are rabbitbrush; it is in the sunflower family and booms in the late summer and fall.

2.2 – We are now crossing into bleached, hydrothermally altered volcanic rocks.

2.8 – On the right is the Geiger clay pit. Clay was mined here from the mid-1940s through 1963 by the Reno Press Brick Company. The clay here is formed when minerals in the andesite rocks that are found in this area are hydrothermally altered. This process breaks down the minerals in the andesite into illite and kaolinite—two types of clay minerals.

2.9 – Notice the bright red outcrops on either side of the highway. This rock is a conglomerate called ferricrete and is composed of smaller rock fragments and clay that are cemented together with iron oxides, giving it its bright red color.

3.4 – We are passing through a zone of dark gray volcanic rock. This is an unaltered section of volcanic flow breccia that was deposited from a volcanic mud flow, otherwise known as a lahar.

4.1 – To the left is a roadcut where dark gray rock sits at an angle on top of altered, lighter-colored rock. This contact represents an alteration boundary where the hot, acidic waters were unable to penetrate the less fractured, dark gray rock.

4.7 – Passing the Geiger Lookout point.

5.3 – We are passing through some sections of very colorful rocks. These rocks are 10 to 14 million years old. In the roadcuts to the left we can see altered rock that has been broken up by faulting.

6.3 – Now entering Storey County!

6.6 – To the right, notice the distinction of piñon and Jeffrey pines on the slopes of the canyon. The Jeffrey pines grow on the north-facing slopes at elevations lower than they normally would because of the acidic and porous ground.

7.8 – Virginia City Highlands is on the left with the eastern end of Toll Road on the right. The broad flat area of the Highlands is an old surface less affected by erosion since the Virginia Range was uplifted.

9.3 – Geiger Summit—elevation 2069 meters (6789 feet). Note the yellow-green lichen covering the cliff-forming outcrops of gray unaltered andesite at 1:00.

9.8 – Passing Lousetown historical marker. Louisa Town was a station along the original Virginia and Truckee toll road. The name was butchered to Lousetown, possibly reflecting the hygiene of the station keepers.

10.1 – The hills to the left (east) are the Flowery Range, which are composed predominately of Miocene andesitic volcanic rocks.

11.1 – Lousetown Road continues to the north, eventually connecting with the Truckee River Canyon and Interstate 80. The rough dirt road crosses Long Valley Creek a couple of times and offers scenic views and some historic ruins. This was the original route of the Virginia and Truckee toll road that connected Virginia City with Lockwood before the completion of the Geiger-Tilton toll road.

11.5 – Comstock ahead! Here we catch our first glimpses of the tailings piles of the Comstock.

11.9 – Crossing Cedar Hill Canyon. Cedar Hill Canyon spring is uphill (to the right).

12.2 – Sevenmile Canyon is to the left and at 10:00 are the Sierra Nevada and Union Mine tailings.

12.8 – Entering the historic town of Virginia City—elevation 1890 meters (6200 feet). Please proceed slowly through the town and watch for pedestrians. Virginia City was known as the Queen of the Comstock and was home to over 25,000 people during its heyday. It is rumored that profits from silver mined from the Comstock built San Francisco through the financing of much of its commerce. Today, the historic district includes Virginia City, Gold Hill, Silver City, and Dayton. While many of the old mining features appear abandoned, remember that most of them are on private property, so please leave things as you find them and respect private property signs.

13.0 – A parking/picnic area is on the left. Feel free to stop here and use the restrooms (just after D Street).

14.0 – **Stop 2 (GPS coordinate: 39.303304°, -119.653297°): Loring pit, Chollar raise, and Comstock fault** Please park off the highway on the dirt. Extra vehicles can park across the street at the Fourth Ward School. Please be careful crossing the street.

14.1 – Turn onto State Route 341, which is marked as the Truck Route to Carson City.

14.2 – Turn left onto F Street.

14.3 – At the Y, keep right to stay on F Street.

14.5 – Cross the train tracks and keep right. Take the first right into the dirt lot. If you reach the large dirt area and the arena, you have gone too far.

14.6 – **Stop 3 (GPS coordinate: 39.304283°, -119.649076°): Arizona Comstock Mill** Park in the dirt lot—you will see signs that read “Gold Mill Parking”.

Depart Virginia City and return to the Galena Junction shopping center to collect vehicles.

Field Stop Descriptions

Stop 1. Steamboat geothermal area (internal stops 1A through 1D)

Geologic overview

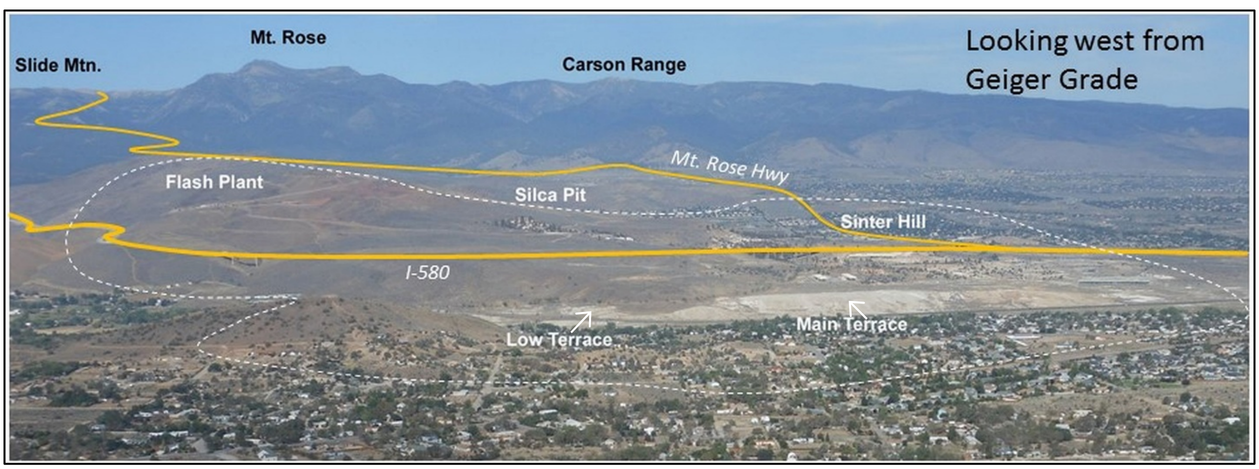

Figure 3. View west across the Steamboat Springs geothermal area approximately shown with the white dashes. We will visit the main terrace, sinter hill, the silica pit, and one of six power plants at Steamboat.

Steamboat Springs, which began producing electricity in 1984, was one of the first geothermal fields developed in the U.S. following enactment of the Geothermal Steam Act of 1970, which allowed for the leasing of federal land for purposes of geothermal energy extraction. Before tapping of hot waters for energy, Steamboat had more than 50 springs, including an active hot spring terrace that featured boiling pools, fumaroles, and even small geysers (figure 3). Historically, the springs were central to the indigenous

Washoe people, who used the Steamboat area for settlement as well as a major source of silica and volcanic stone for toolmaking. Early settlers to the region further developed the hot springs for therapeutic reasons, and for mineral extraction including native sulfur and mercury—the latter was used to concentrate precious metals mined from Comstock Lode ores through the amalgamation process.

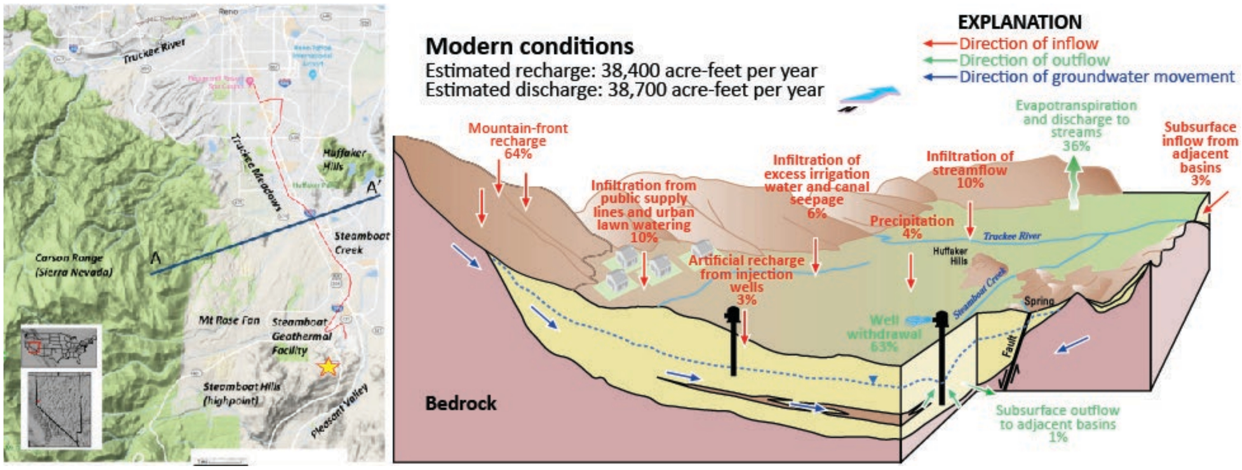

Figure 4. Plan map and schematic cross section showing the sources and fate of water in the Truckee Meadows. The pink unit represents the bedrock in the region, which is overlain by thick accumulations of gravels shown in yellow deposited by streams such as Galena Creek and the Truckee River. Most water for Steamboat is derived from snowmelt in the Carson Range.

The hot water at Steamboat Springs consists mostly of snowmelt derived from the east side of the Carson Range (figure 4). Runoff from snowmelt is carried by Galena, Whites, and Thomas creeks and other smaller drainages before emptying into the Mount Rose alluvial fan, which is the large apron of gravels that Mount Rose Highway climbs between Steamboat Springs and Galena Creek Regional Park. Much of the water seeps into the porous and permeable gravels that make up the alluvial fan, recharging the region's groundwater. Some of this cold, snowmelt-derived groundwater flows under and around the Steamboat Hills, where it circulates deeply along fractures in the underlying granite bedrock. At considerable depth, possibly a few kilometers under the Steamboat Hills, the water is thought to be heated by a small magma body. Heating of the water causes it to convect and rise rapidly in a plume-like form along other fractures that eventually break the surface at Steamboat Springs. We will observe examples of such fractures when we visit the main sinter terrace, which is our first stop at Steamboat. The inference that magma underlies the Steamboat Hills is based on several lines of evidence. The Steamboat Hills contain the youngest volcanic rocks in the Truckee Meadows, dated between about 1.14 and 2.53 million years (Silberman et al., 1979). Although this may seem a long time, the rocks are geologically youthful and indicate that very young volcanism has occurred in the Truckee Meadows (White et al., 1964). Similar young volcanic activity produced the Huffaker Hills and Rattlesnake Mountain to the north. Despite the possibility of magma at depth, geologists consider there to be little or no risk of rejuvenated volcanic activity. Other evidence of magma at depth come from Steamboat's high temperature, chemical tracers in the geothermal waters that are indicative of a magma source, and geophysical imaging of the deep crust under Steamboat.

Young volcanic rocks of the Steamboat Hills are lavas sourced from now-covered local vents. The lavas are of two main compositions: andesite and rhyolite. Andesite is the dominant lava type of classic cone-shaped stratovolcanoes like Mount Shasta, whereas rhyolite is common in large, flat-bottomed volcanoes called calderas. The Long Valley caldera near Mammoth Lakes, California, is a young example of a caldera, and it also contains abundant geothermal features. Both andesite and rhyolite are also found in smaller volcanic features such as at Steamboat. The lavas at Steamboat were erupted through and emplaced on top of older granite and other rocks that make up the Sierra Nevada Mountains and surrounding areas.

Geothermal energy is a form of renewable energy. Unlike petroleum, coal, and other hydrocarbons, geothermal taps energy sources that are continually replenished through natural processes of heat production in the Earth. As such, geothermal is a clean and desired energy source where it can be economically developed. Places like the Great Basin are particularly suitable for geothermal energy because of the high heat flow generated from a very active plate tectonic setting. Such tectonism is also the cause of young volcanism and earthquakes in the region as well as Nevada’s mountainous terrain.

Stop 1A: Steamboat power plant and control center

Steamboat Springs was one of the first geothermal areas intensively studied by the U.S. Geological Survey beginning in the 1950s (White et al., 1964). Much of the early pioneering scientific work at Steamboat was later applied to geothermal centers throughout the world. Later, work here and elsewhere linked some types of modern geothermal systems to major precious-metal ore deposits that formed millions of years ago in tectonically active areas like the Great Basin. Those precious-metal deposits are host to large mines. Examples of these fossil hydrothermal systems include the Comstock Lode (Virginia City; our stop 2), Tonopah, Bodie (eastern California), and Midas (north-central Nevada).

The hot water that drives the geothermal system at Steamboat (figure 6) ranges in temperature from about 280˚ to 132˚ C (480˚ to 270˚ F). Temperatures were higher when the power plants first opened, but because of continuous pumping since the 1980s, peak temperatures have slowly decreased. As a result of the loss in efficiency through time, Steamboat’s six power generation plants together produce more than 65 megawatts (Mw) of energy today. As reference, a 1 Mw plant produces enough energy to support about 470 homes. Power from the Steamboat geothermal power plant complex provides baseload energy to customers in Nevada and southern California.

To generate electricity from hot water, a series of wells must be drilled to great depth (up to 1070 m, or 3500 ft), where water temperatures are much hotter than near the surface. The water is then either pumped to the surface or rises via artesian flow. Some wells at Steamboat Hills are hot enough that the rising water boils as its pressure decreases in the well—similar to the way water boils in a stove pot when the lid is removed. The boiling produces steam, which is then directly used to turn turbines to generate electricity in a “flash-steam” plant. Most plants at Steamboat, however, operate at lower water temperatures and use a different process called a binary system. Binary systems also rely on boiling of a fluid, but instead of water, binary systems use an enclosed secondary or “working” fluid with a lower boiling temperature than water. The boiling working fluid, which is commonly a hydrocarbon like pentane or butane, flashes to vapor, which then drives turbines. The “spent” geothermal water and the working fluid, both in separate pipes, are then cooled in a heat exchanger. The cool geothermal water is injected back into the ground away from the highest-temperature area or “upflow zone”, and the working fluid is then recycled back through the plant, where it is heated again to boiling.

Operators working in the Galena control room at Steamboat monitor power production at Steamboat as well as nearby facilities at Bradys Hot Springs and Desert Peak. They also monitor recovered energy generating facilities located along the Northern Border Pipeline, a natural gas pipeline running from Canada to the Midwest.

Stop 1B: Main sinter terrace

Figures 5. Watch your step! Rare Steamboat buckwheat (left) on main terrace. View of geysers in the main terrace, circa 1986 after power production had begun (right).

The main terrace at Steamboat Springs is a modern or active sinter mound. The lower or eastern flank of the terrace issued hot water until pumping for geothermal energy began in the 1980s, when the springs mostly ceased to flow. Features of the hot spring terraces included steaming pools, fumaroles, and even rare geysers (figure 5) similar to those of other geothermal areas such as Yellowstone. The main terrace is built of a multitude of millimeter-thick opaline silica layers that were deposited as mineral-laden hot water issued from the springs cooled rapidly in contact with the much cooler atmosphere. As such, the topmost layers are the most recently deposited silica sinter, whereas those at the base of the terrace are oldest. Opal, unlike quartz, is a softer form of silica that contains water. Eventually, the unstable opal silica that comprises this terrace will dehydrate to form the fine-grained variety of quartz called chalcedony.

Notice the white, highly porous or “spongy”, interwoven nature of silica that comprises sinter. The sinter deposited in this seemingly inhospitable environment in the presence of the highly tolerant microbes, archaea and bacteria, which are extremophiles (figure 7; Lynne et al., 2008). It is likely that extremophiles synthesize compounds containing sulfur and metals present in the geothermal water.

Another extremophile of sorts is the protected Steamboat buckwheat (figure 5), which is only found in and near the main terrace. Use caution to avoid stepping on these rare beauties! The rare Steamboat buckwheat thrives here in a microclimate of conditions, which is unique to Nevada and the world. Many microclimates exist across Nevada’s vast landscape due to unique geologic, elevation, or moisture conditions. With unique microclimates, unique plant life can thrive. This unique plant life can play host to unique wildlife. For example, blue butterflies (family lycaenidae) exist in many subspecies across Nevada, thriving only on a specific plant like a buckwheat that only lives in a certain area. One such unique buckwheat thrives only at the base of Sand Mountain sand dune in Churchill County. There, and only there, thrives the Sand Mountain blue butterfly, which thrives on the Sand Mountain buckwheat.

Steamboat’s main sinter terrace is cut by a series of parallel fractures. The fractures emit steam, which indicates a hot water table at depth. The steam is accompanied by small amounts of sulfurous gases that are the source of the foul smell in places. Prior to pumping, the fractures served to localize the hot spring flow at Steamboat. In addition to sulfur and opaline silica, the springs deposited minute quantities of gold, silver, mercury and other metals. Such geothermal systems are considered to be modern analogs of ancient eroded systems that formed bonanza deposits like the Comstock Lode, which we will visit in the second half of this field trip.

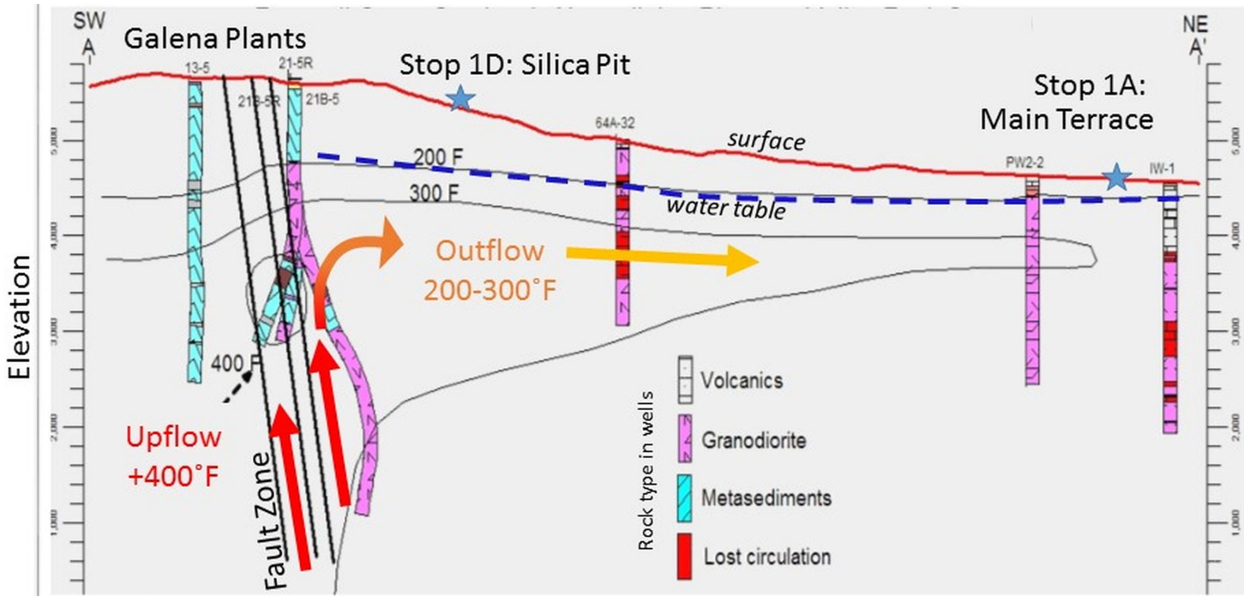

Figure 6. Cross section from the higher elevation power plants above the silica pit (stop 1D) to the main terrace (stop 1A) showing the zone of vertical upflow and highest temperature water. In contrast, the outflow zone extends laterally for several kilometers, losing temperature with distance from the upflow zone.

Stop 1C. High terrace (silica hill) silica sinter

The high terrace is about 122 m (400 ft) higher in elevation than the main terrace, and it is also thousands of years older than the active main terrace (White et al., 1964). The high terrace reflects a time when the water table at Steamboat was at a much higher level. Notice that the silica present at the high terrace has a strikingly different mottled texture than that observed at the main terrace. Sinter ages through time, and the original water-bearing opal silica like that present at the main terrace loses its water and recrystallizes to form a very fine-grained variety of quartz, called chalcedony. Sinter at the high terrace is denser and more compact than the vuggy, lightweight sinter at the main terrace (figure 7). However, note that the original thin layered texture of sinter is still preserved despite the changes, and fossils of bacteria and other microbes are also abundant when viewed under a microscope (figure 7; Lynne et al., 2008).

Figure 7. Sample of chalcedonic quartz from the high terrace. Pendant created by Dana Munkelt. Note the weakly banded and semi-translucent character of the quartz. This quartz is transformed from opal silica that makes up the porous sinter of the main terrace. Note the small red specks, which are composed of cinnabar, a mercury sulfide mineral. The filaments in the right photograph are fossilized bacteria from the high terrace chalcedony. Thousands of years are generally required to transform opal into quartz.

Be careful in breaking these rocks with a hammer as quartz is very hard and has a tendency to splinter into sharp fragments. Eye protection is required if you attempt to break these rocks, and please watch for others around you before you hammer.

The chalcedony quartz is various shades of milky white, light gray, dark gray, and pink. Commonly, the darker gray to black areas are where the mercury-bearing mineral cinnabar is present. The cinnabar is brilliant red when first exposed on a broken surface, but through time it changes to black. Thus, cinnabar at Steamboat is sensitive to light.

Stop 1D. Silica pit

Time and access permitting, we will travel about 1 km (.6 miles) to the south from the high terrace to an area called the silica pit, named after the bleached white rock that characterizes this fairly high-elevation spot. The water table is well below the surface here, at least 30 meters (100 feet) down. Recall that the water table was only a couple meters below the surface at the main terrace, where there is active discharge by hot springs. The water that is present beneath the silica pit and Steamboat Hills to the south is much higher temperature than the near-surface water at the main terrace. The water is hotter here because the silica pit is closer to the upflow zone of the Steamboat geothermal system (figure 6). The hottest wells are located under the higher parts of the Steamboat Hills and support the steam turbine and Galena II plant. The high water temperature at silica pit means that it is at or very near its boiling point at the water table. When steam separates from liquid water through boiling in a geothermal system, it carries with it not just water in vapor form but lots of other gases including carbon dioxide, sulfur dioxide, and hydrogen sulfide. The sulfurous gases permeate through the overlying rock. As these gases cool, they may condense to highly acidic water from the abundance of sulfur. This acid water is highly caustic and reacts with the bedrock to destroy most of the original minerals that make up the rock except for quartz, which is resistive to acids. The result is a soft, bleached white rock composed mostly of a mixture of new silica and residual quartz from the original bedrock. The white, soft material you observe at silica pit is the result of acid attack on bedrock and is characteristic of rocks that overlie a near-boiling water table. Walking up the hill a short distance from the silica pit, one can sample native sulfur that formed in cracks when the sulfurous gases condensed as they cooled. To the immediate east of the silica pit is an area that was mined for mercury during the Comstock period. The mercury was necessary at the time for the extraction of gold and silver from the Comstock ores.

Natural hazards in and around the Truckee Meadows

Fires

There have been a number of fires in the Truckee Meadows, Pleasant Valley, and Washoe Valley over the past several years, with many of these fires are occurring outside of normal fire season. For example, the Caughlin Ranch Fire and the Washoe Fire were ignited on November 18th, 2011 and January 19th, 2012 respectively. The Caughlin Ranch Fire burned approximately 1935 acres, destroyed 28 homes, and damaged 15 homes. An additional 4500 homes were threatened (Reno Fire Department, 2011). This fire was caused by arching power lines during a high wind event. The Washoe Fire burned approximately 3900 acres and destroyed 26 homes in and around Pleasant Valley. Improperly discarded fireplace ashes were the cause of this fire. At the height of the Washoe Fire, 10,000 residents were asked to evacuate (Snyder, 2012), and the fire threatened the Steamboat geothermal power plant.

The foothills around Reno are considered a part of the Wildland Urban Interface (WUI). WUI Fires are fires that occur and cause damage in areas where urban development encroaches on undeveloped wildlands. The weather in the Truckee Meadows and surrounding areas often plays a part in amplifying these fires with low humidity, wind, and hot temperatures during the summer months. However, these recent incidents show that the fire hazard exists year-round. While lightning strikes account for some fires in our area, the majority of fires are human caused and can be prevented.

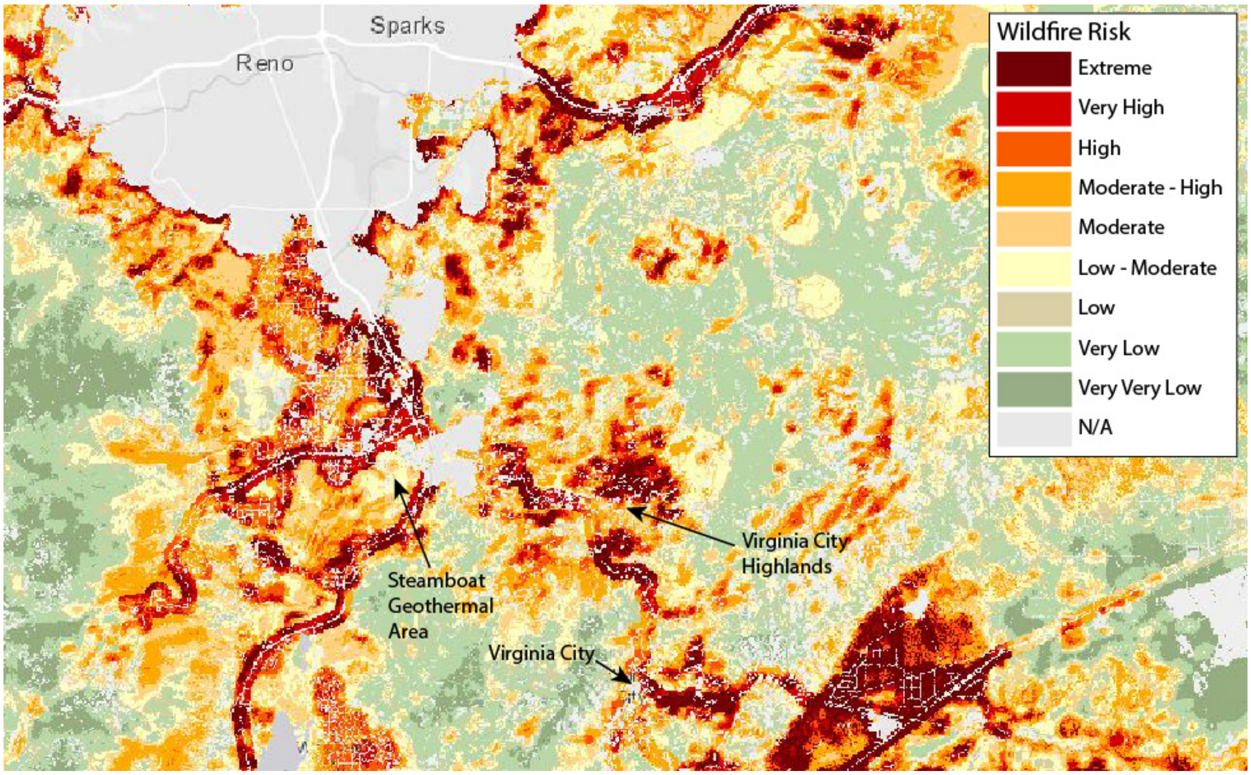

Figure 8. Wildfire risk map of the central and southern portions of the Truckee Meadows, Pleasant Valley, eastern Carson Range, Virginia City, and Virginia City Highlands. From the Nevada Division of Forestry Natural Resources and Fire Information Portal web map (Nevada Division of Forestry, undated).

The Virginia City Highlands are located in an area of extreme wildfire risk (figure 8). In 2015, there were approximately 1500 residents living in this community. Certain mitigation actions have been identified to reduce the wildfire risk to this community which include the construction of fuel brakes (removing strips of flammable vegetation) throughout the subdivision (Storey County, 2015).

Some causes of wildfires are listed below:

- Fireworks
- Target shooting
- Campfires
- Improperly stored equipment
- Parking hot vehicles on top or dry vegetation
- Power lines

For more information and to learn how to reduce wildfire risk and protect your home, visit https://www.reno.gov/government/departments/fire-department/fire-prevention/wildfires-and-living-in-the-wildland-urban-interface.

Landslides

Slide Mountain, named for the large landslides that have occurred on its southeastern face over time, is located south of Mount Rose. The most recent of these landslides occurred on May 30, 1983, when approximately 1,400,000 cubic yards of rock detached from the mountain and slid into Upper Price Lake, displacing the water (Glancy and Bell, 2000). The water traveled down Ophir Creek to Lower Price Lake, which in turn overflowed sending floodwaters down the narrow channel of Ophir Creek. As the water traveled downslope, it incorporated snow, vegetation, rocks, mud, and more water creating a 20- to 30-foot-high, 200-foot-wide wall of debris. The debris fanned out as it reached the flat-bottomed Washoe Valley and covered Old Highway 395 (figure 9). One person was killed, and 4 others were severely injured. Several homes were destroyed or damaged. The slide and resulting flood caused over $2 million in damages (Glancy and Bell, 2000).

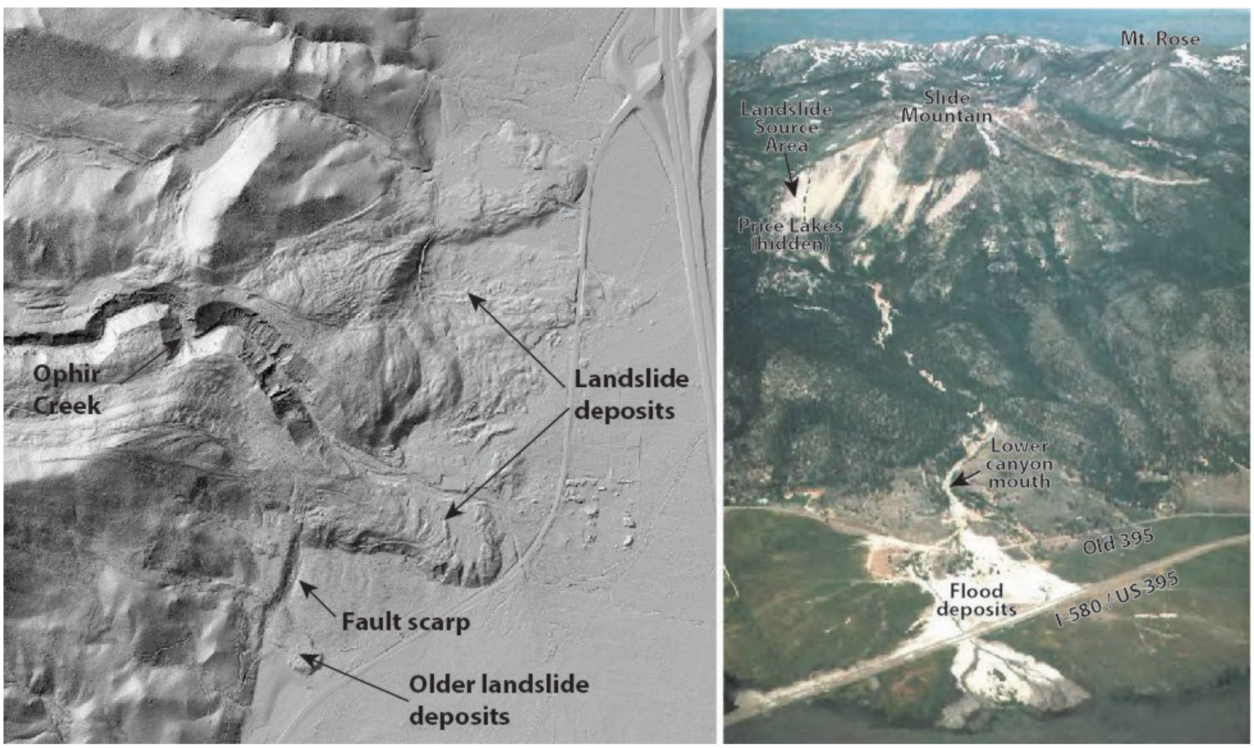

Figure 9. Digital elevation model (DEM) showing the location of landslide deposits and fault scarps relative to the Ophir Creek drainage (left). Oblique view of the extent of the 1983 landslide and flood in Washoe Valley (right).

Several factors contributed to the landslide and resulting flood. The winter of 1982–1983 left a heavy snowpack in the Carson Range, and the unseasonably warm weather that occurred in late May sped up the snowmelt. The excess water seeped into joints and cracks in the bedrock that composes Slide Mountain, increasing hydraulic pressure within the bedrock. This increase in pressure and gravity caused the side of the mountain to fail, sending a wall of rock downslope (Glancy and Bell, 2000).

New Lidar collected for the greater Reno–Sparks–Carson City area shows additional evidence of landslides and debris flows associated with Slide Mountain. We are now able to clearly see additional landslide deposits, both large and small scale. These new Lidar images also show geologists that fault scarps in this area have been covered by landslides. The question remains: were these landslides triggered by the same earthquakes that caused the fault scarps, or did they occur at separate times?

Earthquakes

Some geologists estimate the earthquake risk in the Truckee Meadows is approaching the earthquake risk of San Francisco (Lin, 2019). The Truckee Meadows is situated along the northern end of the Walker Lane seismic belt, an area of predominately strike-slip motion that takes up roughly 20% of the plate motion between the North American and Pacific tectonic plates. The other 80% of the motion occurs along the San Andreas Fault (Totten, 2019).

Historically, there have been several large earthquakes in the Truckee Meadows and surrounding areas. However, the region has been relatively quiet for the past 70 years. Apart from the ~M5.0 earthquake that occurred during the 2008 Mogul earthquake swarm, the last significant earthquake to occur in the Reno area was in 1948 when a M6.0 occurred near Verdi. Prior to that, M6.0 and M6.4 earthquakes occurred in Reno on February 18, 1914 and April 24, 1914, respectively. These earthquakes caused damage in the Reno and Virginia City areas, and the M6.4 earthquake was reportedly felt in Sacramento (The Great Nevada Shakeout, undated).

While it has been quiet for the better part of a century, Nevada is earthquake country. There are several precautions residents of the Truckee Meadows and western Nevada can take to protect themselves against future earthquakes. Learn more about Nevada's earthquake hazard and preparing for future earthquakes at http://pubs.nbmg.unr.edu/Living-with-earthquakes-in-NV-p/sp027.htm.

Volcanism

As mentioned briefly in the geologic overview at stop 1, Huffaker Hills and Rattlesnake Mountain were produced by young volcanic activity. These hills are part of a group of cone-shaped volcanic domes and related andesite flows that were part of a composite volcano complex (Tingley et al., 2005). Southeast of Huffaker Hills and situated slightly away from the Virginia Range is a very young (geologically speaking) rhyolite dome that is currently being mined for lightweight aggregate (noted at mile marker 0.9 in the road log).

Mount Rose is the prominent peak located southwest of Reno and the Truckee Meadows. It is the highest peak in the northern portion of the Carson Range at an elevation of 3287 m (10,778 ft). The highest point in the range, Freel Peak located in the southern portion of the range, is only a few meters higher at 3317 m (10,881 ft). This subrange of the Sierra Nevada is bounded by faults and basins on either side (Lake Tahoe to the west and the Truckee Meadows, Eagle Valley, and Carson Valley to the east). Mount Rose has been referred to as an extinct volcano, and although the peak is capped with locally sourced volcanic rocks, the mountain itself is not a volcanic vent. The andesitic lavas that cap Mount Rose came from a nearby extinct vent located to the north at Gray Creek. These 6 to 7 million year old volcanic rocks rest atop the much older and very extensive granitic rocks (Hinz and Ramelli, 2015) that comprise the foundation of the Sierra Nevada, referred to as the Sierra Nevada batholith by geologists.

Lunch at 'Pine Basin'

Ponderosa and Jeffrey pines are two very closely related species of pine that can be found throughout the eastern Sierra Nevada and portions of western Nevada. Because of their similarities, these two trees are commonly lumped into a single term: "yellow pine". Ponderosa pines (*Pinus ponderosa*) have a larger range than Jeffrey pines (*Pinus jeffreyi*) and are found across the west, extending from Baja California into British Columbia, while Jeffrey pines are usually only found in the eastern Sierra Nevada and related ranges (Tingley et al., 2005). To further confuse the issue, ponderosa and Jeffrey pines occasionally hybridize, creating a cross between the two. While these two pine species might be considered identical to the untrained eye, they can be differentiated by their cones. The barbs on ponderosa pine cones point outwards whereas the barbs on a Jeffrey pine cone point inward – remember, "gentle Jeffrey and prickly ponderosa". The bark of a Jeffrey pine also gives off a wonderful scent, which has been described as vanilla or butterscotch. While we break for lunch, smell the bark of these pines and take a look around to see if you can spot any pine cones. Are these Jeffrey pines or ponderosa pines? Or are they a mixture of both?

Stop 2. The Loring pit, Chollar raise, and Comstock fault

Abandoned mines and bat habitat

There are hundreds of thousands abandoned mine features located throughout Nevada and thousands of them can be found on the Comstock alone. Abandoned mine features include shafts, adits (horizontal mine openings), open pits, stopes, trenches, and prospect pits. Many historic mines pose a significant hazard to humans and animals. Hazards associated with abandoned mines include falling, cave-ins, explosives, poisonous or deadly animals (rattlesnakes and cougars), rotten timbers, water, and bad air. The Nevada Division of Minerals (NDOM) runs the state's Abandoned Mine Lands Program (AML) and works towards securing these hazards. According to NDOM, there have been zero reported injuries of fatalities associated with AML features since 2013; over 100,000 historic mining features have been inventoried; and they have cataloged nearly 23,000 hazardous AML features with over 80% of those being safeguarded or secured to date. NDOM works with other state and federal agencies in Nevada to accomplish this never-ending task, and they hire interns each summer to assist with inventory and securing.

Figure 10. A bat cupola, constructed in 2012, serves to both protect and preserve bat habitat while guarding humans against the hazards abandoned mines pose to humans and animals.

Many of the old mining features you see in the Virginia City area are fenced with barbed wire and t-posts, with warning signs posted around the mines (if they haven't been stolen or vandalized). Openings of some old mines are secured with more permanent methods, which can include bat-compatible closures such as a bat gate or cupola, which we will see at this stop (figure 10). Bat-compatible closures are constructed at AML features where there is an established bat habitat. This is done to not only keep people from entering the AML feature and risking injury or death, but to protect the bats living in these mines. There are 23 bat species found in Nevada (figure 11) and many populations use abandoned mines to roost, raise their pups, and hibernate (Hyslop, 2015) since these old mines offer stable microclimates and protection from weather and predators.

Figure 11. The Townsend's big-eared bat (Corynorhinus townsendii) can be found roosting in abandoned mines. During the summer, the females form maternity colonies, roosting in groups as seen here. Roosting together helps bats keep a higher body temperature that facilitates the rearing of bat pups. Pups rely on their mothers during the first 6 to 8 weeks of life before they are able fly and to forage for food on their own (via Great Basin National Park Facebook Page, photo by Joseph Danielson).

Bats are also incredibly important to our ecosystem, controlling insect populations including some of the most damaging agricultural pests. Some bat species are also valuable pollinators (Bat Conservation International, undated). When people enter abandoned mines that are home to bat populations, they run the risk of waking the bats up if they are hibernating. When bats hibernate, they enter a state of decreased physiological activity (called torpor) for three weeks at a time. The bats then wake for two days to drink water and mate before resuming their slumber. During torpor, the bats burn very little energy, but the process to wake is very energy intensive. If they wake more frequently, as can happen if disturbed, the energy they stored to make it through the winter becomes depleted and the bats can die. In addition to waking the bats during torpor, humans can also transmit disease. One such disease is called white-nose syndrome and is caused by a fungus. The fungus infects the bats, leaving white patches on their noses and wings, and dehydrates the bats forcing them to wake from torpor every week, rather than every three weeks. So far, white-nose syndrome has only been found east of the Rocky Mountains with one isolated case outside of the Seattle, WA area. The disease was discovered near Albany, NY in 2006 and was likely inadvertently introduced from Eurasia (Raff, 2019). Since its introduction, it has spread west to at least 36 states and has killed off whole colonies of bats. The fungus can travel from one cave, or mine, to another on people's boots and clothes. More than 6 million bats have died from this disease in the U.S. and Canada (Robbins, 2019).

General geology of the Comstock Lode

Virginia City and Nevada's early statehood owe their existence to the discovery of extremely rich silver and gold, or bonanza, veins in 1859 in the Virginia Range. Total production from the Comstock is approximately 192 million ounces of silver and 8.3 million ounces of gold (Hudson et al., 2009), most of which occurred during the boom years between 1860 and 1890. Prior to the major Comstock discovery of 1859, small discoveries of gold were made in 1857 and 1858 by miners working in the Gold Hill area to the south. Many of the early Comstock miners had originally come from California and migrated to Nevada after the Mother Lode Gold Rush had largely played out.

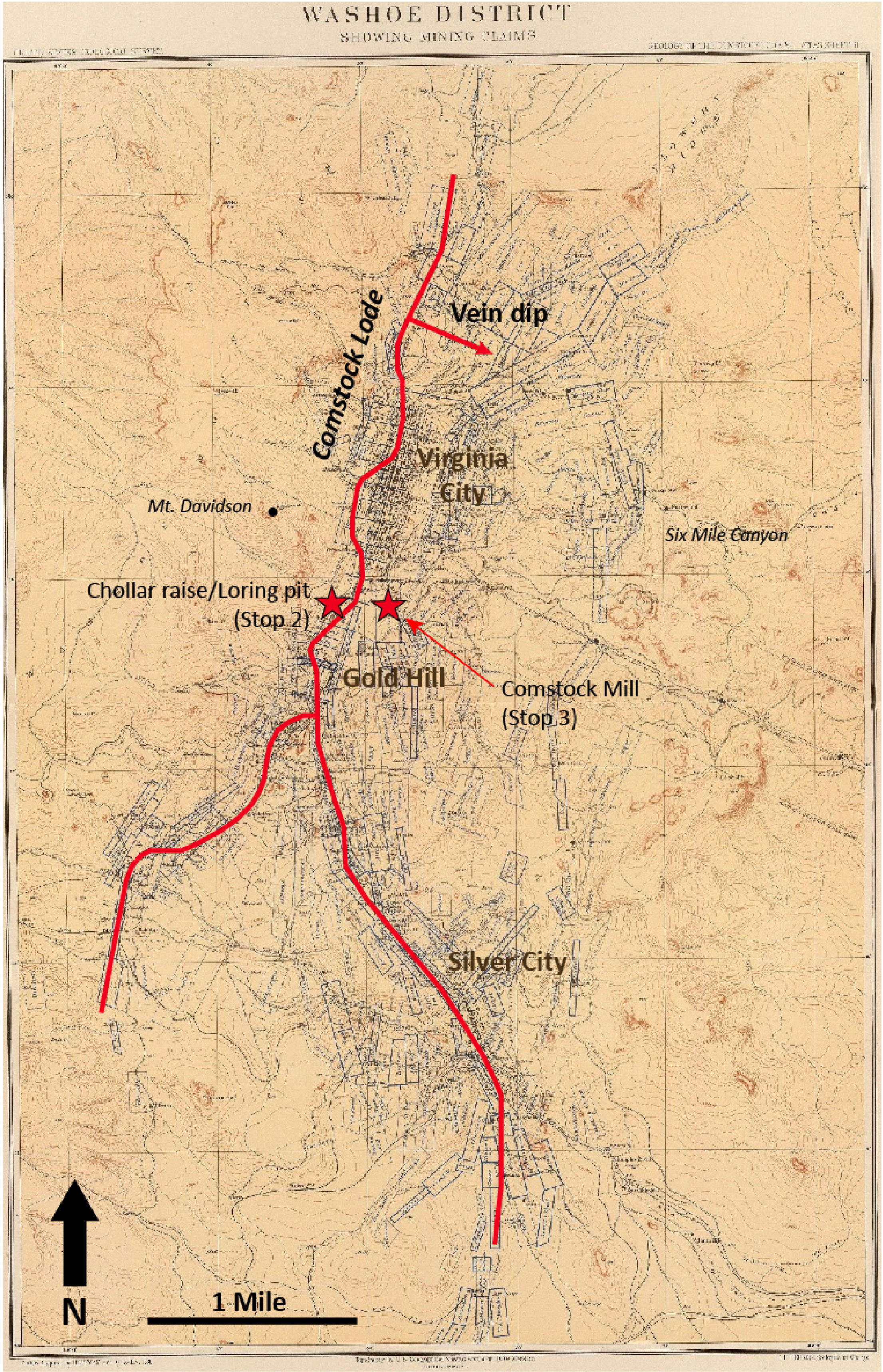

Figure 12. Mining claim map from George Becker's 1882 U.S. Geological Survey monograph of the Comstock Lode. The claim outlines delineate the location of the Comstock fault and its southern splay, the Silver City fault. Note the irregular or corrugated pattern of the Comstock fault (shown as red line). This irregularity likely contributed to the localization of bonanza shoots shown in figure 13 (Long Section).

The name Comstock Lode refers to a belt of bonanza ore shoots (figures 12 and 13) that occur along the east flank of Mount Davidson, the prominent peak that rises about 510 meters (1700 ft.) above Virginia City. The ore shoots occurred like pearls on a string along a 6-km-long (3.7 mi) section of the Comstock fault. The fault is a major planar break in the earth's crust that is oriented northeast and dips about 40˚ to the southeast (Becker, 1882). The Comstock fault is typical of many faults in the Great Basin, which are characterized by movement down the inclined plane of the fault. Such "dip-slip" movement on faults resulted in the topographic pattern of deep valleys and narrow, high mountain ranges distinctive of

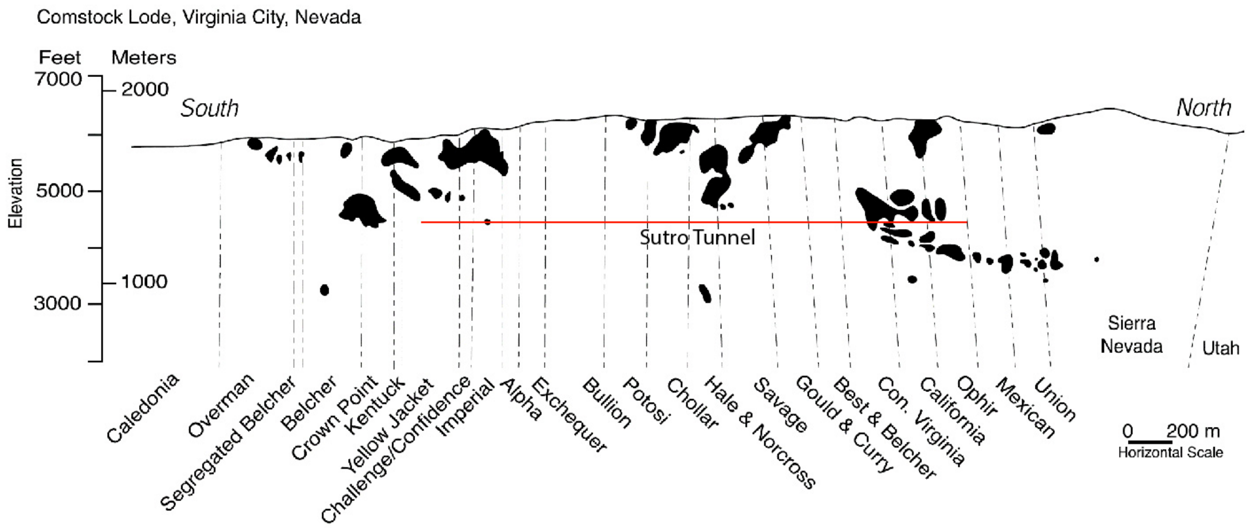

Figure 13. A section along the plane of the Comstock Lode and fault zone showing the names and shapes of the high-grade, or bonanza, gold and silver deposits. Note that the bonanza zones do not occur everywhere along the Comstock fault. Intersections with other faults and perturbations in the fault orientation controlled the distribution of bonanza stopes. Many of the bonanza ore shoots are "blind", which means that there was little or no surface indications for what lay below. This made exploring for and developing many Comstock mines very difficult despite the knowledge that the Comstock fault was the ultimate ore control. Many of the bonanza shoots were discovered only through prospecting along the Comstock fault by underground tunneling. The Sutro Tunnel (red line) was primarily constructed to drain water from the deeper levels of Comstock mines. The Sutro emptied four miles east in Six Mile Canyon near Dayton. Modified from Becker (1882).

Nevada. The *footwall*, or the rocks that lie under the Comstock fault and under Mount Davidson, consist in part of a type of granite called diorite. These granites were once magma that cooled slowly several kilometers beneath the surface about 15 million years ago. The *hanging wall*, or those rocks resting above the Comstock fault, are mostly volcanic rocks, many of which are lava flows that were erupted onto the surface during the same pulse of magmatism that formed the diorite of Mount Davidson. This intense period of magmatism resulted in widespread igneous rocks throughout western Nevada and eastern California; this magmatism is older than but closely related to the modern Cascade volcanic chain, which includes active volcanoes at Lassen Peak and Mount Shasta. Geologists refer to the older volcanic chain as the Ancestral Cascades.

Hydrothermal activity similar to what we observed earlier today at Steamboat Springs, was focused along the Comstock fault zone. However, the Comstock hydrothermal activity is much older than the silica sinters formed today at Steamboat. Through measuring radioactive decay of certain elements in ore-related minerals, geologists have determined the age of gold and silver mineralization at Comstock to be about 14.1 million years old, or Miocene in age (Castor et al., 2005). The mineralization was coincident with magmatism associated with the Ancestral Cascades. Many other major mining districts in the region contain ore deposits formed during this same period of magmatism including Tonopah, Goldfield, and Bodie.

Because Comstock is much older than Steamboat, erosion has stripped the near-surface expressions of hydrothermal activity. There may very well have been sinter terraces like the ones observed at Steamboat at the surface of Comstock during mineralization. The erosion was a benefit to Comstock prospectors and miners in allowing the more productive and bonanza roots of such hydrothermal systems to be exposed. Today, we see evidence of the Comstock hydrothermal system by the abundance of quartz veins that contain minerals with silver, gold, lead, zinc and copper. The quartz veins map the network of fractures that hydrothermal fluids permeated, especially along the Comstock fault and its hanging wall. These hot, mineralizing fluids, by their caustic nature, damaged the rocks that they exploited. The resultant rocks affected by hydrothermal fluids are clay-rich and are expressed with the vivid red, orange, and yellow coloration characteristic of many mining districts in Nevada. These colorful rocks define the overall extent of the hydrothermal systems, and are commonly hundreds, if not thousands, of times larger than the areas that contain economic concentrations of metals. Recall the abundant red and orange rocks that we crossed while driving up Geiger Grade; these are hydrothermally affected rocks of a system related to but slightly younger than Comstock.

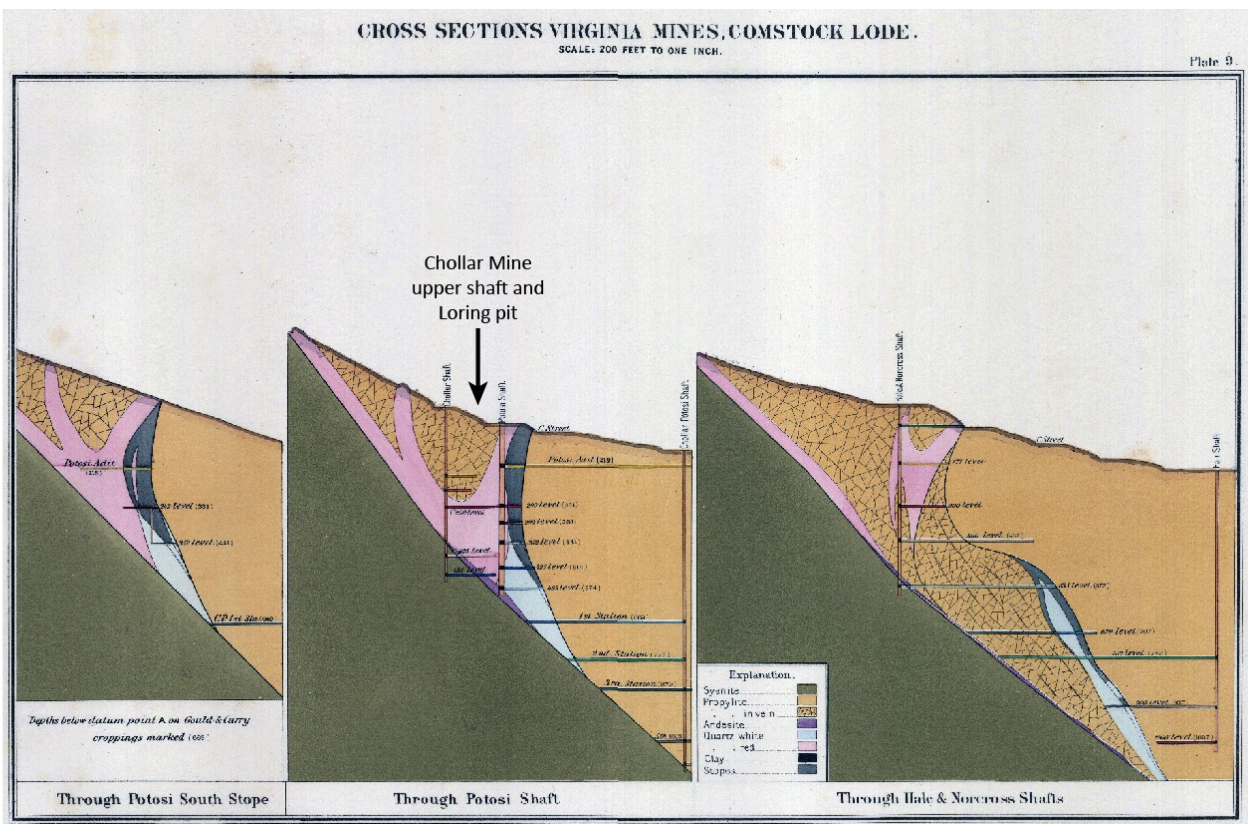

Figure 14. Geologic cross sections perpendicular to the Comstock fault. The footwall consists mostly of the Mount Davidson diorite (shown in dark green). The orange unit represents volcanic rocks in the "hanging wall" of the Comstock fault. The Comstock fault is shown with patterns, whereas pink and blue areas depict large quartz bodies. Note that the quartz bodies in parts of the Comstock Lode were more than 250 feet thick in places and were v-shaped. The shapes were due to splaying or "horsetailing" of the Comstock fault in its upper parts. The great thickness and persistence of quartz veins along the Comstock fault contributed to making the Comstock Lode one of the world's great ore deposits. The middle section is taken from the Chollar shaft, which is Stop 2. Figure is from Becker (1882).

The Chollar raise and Loring pit are located near the middle of the Comstock Lode where the Comstock fault intersects the surface at the foot of Mount Davidson. High-grade gold and silver-bearing quartz veins projected to very near the surface making ores at the Chollar Mine much easier to exploit (figure 14). The Chollar was just one of several bonanza ore shoots, or zones of high-grade silver and gold deposits, along the Comstock fault (figure 13). Following the boom years between 1860 and 1890, sporadic underground mining occurred at Chollar and other mines of the Comstock. In June 1934, under the direction of William Loring and Richard Squires of the Arizona Comstock Corp., an open cut was initiated to mine lower grade ores at higher tonnages, with ores treated at the then-newly constructed Arizona Comstock mill. Open pitting lasted until early 1938, when the mine closed under the weight of low ore grades and lower than expected metal recoveries.

The Chollar property sat idle for about 40 years before new exploration resulted in construction of the Chollar raise in 1979 by United Mining Corp. The new shaft provided underground ventilation and a secondary escapeway for the historic Chollar, Potosi, Hale & Norcross, and Gould & Curry mines, which had a main access point in a drift collared near the Arizona Comstock mill. The new mine, called the New Savage, was dedicated by Nevada Senator Howard Cannon on July 11, 1981 and over a year's time, about 10,000 tons of ore had been processed. As fate would have it, a drop in silver prices forced the mine's closure in January 1983; it reopened again in late 1983 with plans to re-initiate surface mining in the Loring pit, but low gold and silver prices led to its re-closure in April 1985.

The silver at Comstock occurs in numerous forms including as mixtures of silver and gold alloys, called electrum, as native silver, and in various sulfide minerals such as acanthite, polybasite, and galena. These silver-bearing sulfide minerals are commonly metallic gray in color, which contrasts with pyrite (iron sulfide) that forms dull yellow cube-shaped crystals, sphalerite (zinc sulfide) that has a black, resinous color, and chalcopyrite (copper-iron sulfide), which is bright yellow and often mistaken for gold. Figure 15 shows typical bonanza ore from deeper levels of the Comstock. Shallower ores, called red ores, result from oxidation of metallic sulfide minerals in the same way that rust affects steel. We will walk from the Chollar raise shaft to exposures of the Comstock fault and vein system in the old Loring pit. The exposures here contain low grades of silver and gold in white quartz vein rock. This material was planned to be mined by United Mining Corp. in 1985 had it not been closed due to low metal prices. Unlike the chalcedonic sinter quartz found at Steamboat, quartz exposed along the Comstock Lode is coarsely crystalline because of its higher temperature of formation. Commonly, well-formed crystals of quartz a centimeter or more are present in Comstock Lode vein rock.

The Comstock fault and its numerous splay veins dip steeply where observed in Loring pit, but the veins shallow a short distance below the pit, where the dip is a moderate 40˚. This moderate east dip (figure 14) is quite a bit steeper than the topography that grades downward into Six Mile Canyon. Thus, miners accessing the eastern parts of the Comstock Lode had to construct deeper shafts, some as much as a kilometer (3,300 ft) deep, which were costly because of highly unstable ground, abundant water, and high-temperature. The deep shafts were not only risky ventures in terms of mitigating poor ground conditions as the Comstock mines matured by the 1870s, but they were risky investments because there was no guarantee that the bonanza ores would continue to these deep levels. Indeed, by the 1880s and 1890s, it became clear that the bonanza deposits that so characterized the higher levels of the Comstock diminished in size and grade with increased depth. The Sutro Tunnel, which was designed to access deeper levels of Comstock mines and to drain mines flooded by too much water, proved largely unsuccessful because of the diminished ore quality at the depths it was driven.

Figure 15. Typical high-grade or "bonanza" ore from the Comstock Lode. The gray and gold patches are composed of silver-rich sulfide minerals and electrum, which is a naturally-occurring gold-silver alloy. The ores also contain high amounts of copper, lead, and zinc, all of which occur in other sulfide minerals such as chalcopyrite, galena, and sphalerite. Pyrite (iron sulfide) is also abundant as brassy cubes. The white areas are quartz, and the green patches are mixtures of quartz and the minerals chlorite and sericite, which are associated with the ores but do not carry metal values.

Stop 3. Comstock Mill

The Comstock stamp mill is the site of the Arizona Comstock flotation mill that operated starting in 1933. It is one of the last mills constructed on the Comstock, most mills dating back to the mid- to late 1800s. The original mill was built by the Arizona Comstock Corporation to process lower grade ore from the Hale & Norcross underground workings, but by 1934, most mining shifted to the surface at the Loring pit using a diesel shovel and 10- and 20-ton trucks in order to process more ore. The Loring pit is located in the uppermost reaches of the Chollar ore shoot (stop 2; figure 14).

The Arizona Comstock mill used a flotation process to separate the dense precious metal-bearing minerals from waste material, which is called gangue. Arizona Comstock was the first flotation mill erected on the Comstock. The process would "float" heavy ore minerals in a frothy surfactant layer at the top of large flotation tanks because the ore minerals were hydrophobic ("water-hating") and attracted to the surfactant, whereas most gangue or waste minerals were hydrophilic ("water-loving") and would sink. The heavy minerals were thus skimmed from the surface layer, and a heavy mineral concentrate would then be sent to a smelter for refinement to produce relatively pure metal. Although during its first year, the Arizona Comstock mill successfully recovered about 81% of the gold and 57% of the silver in the ores it treated, later poorer recoveries resulted from treating the open pit ores. This, coupled with the high cost of mining, yielded only small profits. Furthermore, a stock scandal in 1937 made it nearly impossible for the company to raise investor money, and both the mill and mine were closed in early 1938. The mill was recommended for modernization, including the installation of a cyanide circuit and a more robust crusher, but the funds necessary for full renovation were never delivered due in large part to the stock scandal. The Arizona Comstock mill sat idle during World War II while the few other operating mills and mines on the Comstock were under closures mandated by the 1942 Limitation Order L-208, which restricted mining to only commodities deemed critical for the war effort (Limbaugh, 2015).

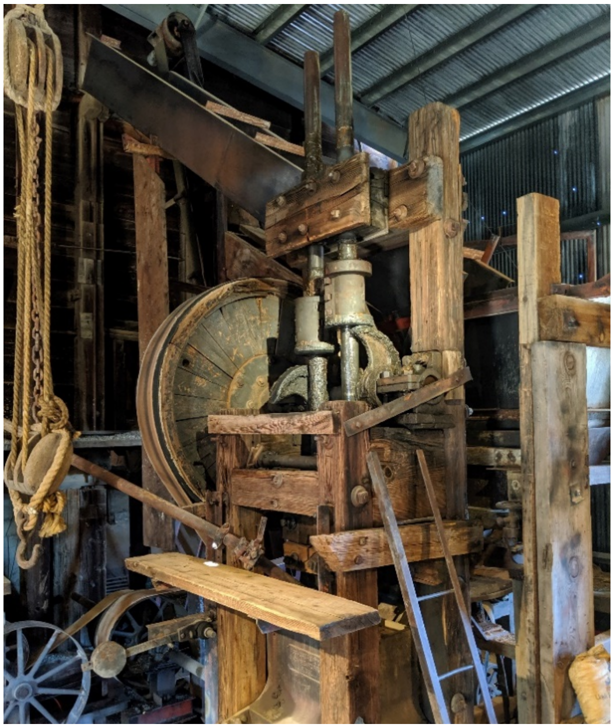

Figure 16. The current two-stamp mill at the Comstock mill.

Over the last several years, the Arizona Comstock mill site was significantly renovated. A historic 2-stamp mill from the Murietta mine near Goldfield, Nevada was installed in a building adjacent to the Arizona Comstock mill (figure 16). The stamp mill was made operational for educational purposes. Stamp mills were the primary way that most Comstock ores were crushed as a first step in the process to extract gold and silver, although the earliest mills were arrastras (a primitive mill for grinding ore), which ground ores by rolling mounted rock cylinders over the top of ores. The stamps are steel cylinders that operate like pistons to crush ore into small fragments and even rock powders, which were then amenable to metal extraction. Large mills on the Comstock had as many as 60 stamps and could crush several hundred tons of ore per day. Early stamp mills used mercury following fine crushing to amalgamate to gold and silver particles. The metal amalgam containing gold and silver was then heated to volatilize the mercury and recover the precious metals. Later processes utilized cyanide extraction instead of mercury.

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