Guide for the Earth Science Week Field Trip, October 16th, 2016

Nevada Bureau of Mines and Geology Educational Series E-59

A River Runs through It—Geology along the Truckee River Valley from Reno to Pyramid Lake

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2016

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 get the Gold Building from downtown Reno, take US-395 North to Exit 71 for Dandini Blvd. Follow Dandini Blvd. east, veer right onto Raggio Pkwy, 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**, and following some introductory comments, route plans, and discussion, we will start driving by **9:00 am**. The Gold Building has a free parking lot, and we encourage field trip participants to carpool and/or leave extra cars in the parking lot. Although most of the roads are passable without four-wheel drive, several stops require higher clearance. At those stops, participants may want to consider leaving their car at the turnoff and riding the short distance to the stop with others.

Figure 1. The course of the Truckee River from Lake Tahoe, California to Pyramid Lake, Nevada.

Road Log mileage 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. Please bring a pack lunch, water, sturdy shoes, jacket, camera, and a smile.

INTRODUCTION

This field trip will follow the route of the Truckee River canyon from Reno to its terminus at Pyramid Lake (figure 1). From Pyramid Lake, the trip then continues southwest across the Virginia Mountains and south through Warm Springs and Spanish Springs valleys back to Reno.

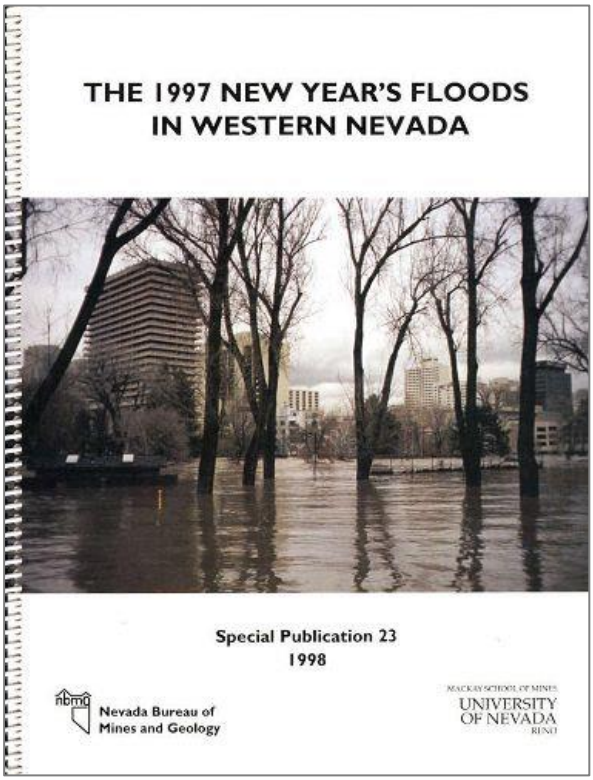
The Truckee River is sourced from Lake Tahoe at an elevation of 6,233 ft (1,900 m) in the Sierra Nevada and flows 121 miles (195 km) to its terminus at the southern end of Pyramid Lake at elevation 3,793 ft (1,156 m). The river's drainage basin encompasses around 3,060 sq. mi. (7,925 km^2) and gets its name from the Paiute chief, Truckee. The Truckee River is the main source for agriculture irrigation and residential water needs in the Reno region and is susceptible to extreme flooding, especially during heavy winter rain storms. As a result, the flow of the river is regulated by a series of dams east of Truckee, California, including Boca Reservoir, Stampede Reservoir, Prosser Creek Reservoir, and Martis Creek Reservoir. Water transmission flumes line the upper part of the river and are susceptible to damage from rock fall and strong ground shaking during local earthquakes.

Many historic floods have affected the Truckee Meadows (Reno basin) area, including major events in 1862, 1875, 1890, 1904, 1907, 1928, 1937, 1943, 1950, 1955, 1963, 1986, and 1997. The devastating "New Year's flood" of 1997 caused over 450 million dollars in damage and closed downtown businesses for weeks (figure 2). This event was caused by a phenomena known as the "Pineapple Express" in which

several warm storms from the Hawaiian Islands produced heavy rainfall in the Sierras, saturating and melting the snow pack and resulting in flows around 18,000 cfs.

During the trip we will discuss historic flooding history, paleo–Lake Lahontan timing and stratigraphy, the connection of Pyramid Lake to Lake Lahontan, Neogene tectonics and paleovalley offsets, recent tectonics and earthquake hazards, and bedrock geology. We will also have an opportunity to hunt for macroscopic fossils preserved in 15-million-year-old diatomite.

Figure 2. Photographs of the great "New Year's flood" of 1997 in Reno, Nevada. The flood was caused by a rain-on-snow event, which catastrophically melted much of the snow pack.



To learn more about the "New Year's floods" of 1997, see NBMG Special Publication 23, *The 1997 New Year's Floods in Western Nevada*. This publication is available at http://pubs.nbmg.unr.edu/1997-New-Year-s-floods-w-NV-p/sp023.htm

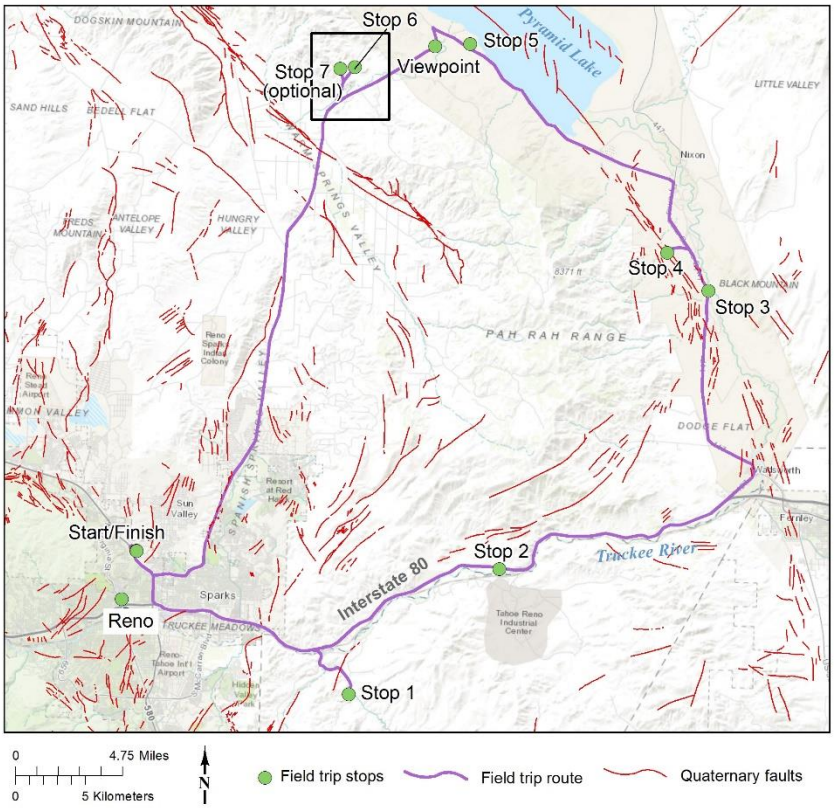


Figure 3. Map of the field trip route showing stop localities (left). Black rectangle shows area of the above Google Earth image, which shows detailed route of stops 6 and 7.

ROAD LOG (see figure 3 above)

<u>Start and finish of trip is the Gold Building (GPS coordinate: 39.57175604°, -119.802847°)</u>

ZERO miles at the Gold Building.

0.0 – Turn right onto Raggio Pkwy, then turn left onto Dandini Blvd., and at 0.5 miles turn left onto US-395 South.

3.3 – Take Exit 40 and merge onto I-80 East.

7.1 – To the left (north of I-80) is Sparks Marina, which was formally known as the Helms gravel pit. This quarry provided rock for nearby construction and road projects since 1968, but it was flooded in the "New Year's flood" of 1997. Since then, it has remained a public marina and swimming hole.

8.8 – Just crossed the Vista fault, which bounds the eastside of the Truckee Meadows.

9.2 – Entering Truckee River Canyon. The river has deeply incised through the Virginia and Pah Rah ranges exposing the bedrock geology.

11.4 – Take Exit 22 for Lockwood; turn right toward the community of Lockwood, which is built on a low terrace of the Truckee River. Periodic historic flooding events have affected the community.

12.1 – Entering Lagomarsino Canyon; on the right, ~1.4-million-year-old McClellan Peak basalt flows are visible capping the ridges.

14.9 – **Stop 1 (GPS coordinate: 39.483376°, -119.622478°): Washington Hill rhyolite dome and McClellan Peak basalt** Park in the dirt parking lot and we will examine the rhyolite and basalt volcanic deposits that are visible in all directions. Following this stop, return toward I-80.

16.1 – Scads of basalt are visible on either side of the road, and cap the ridges in front and to the left as you drive back toward I-80.

18.1 – Turn right to merge onto I-80 East.

19.1 – Basalt is visible on the low ridge to the north of I-80.

23.3 – Here is a scenic view of the Truckee River; the layered rocks on the right (to the south) are part of an eroded dacite dome.

24.8 – At the base of the ridges in front of you (left side of highway) is the Olinghouse fault zone, which is a left-lateral strike-slip fault that may have ruptured during an earthquake in the 1860s.

26.2 – To the right is the Frank A. Tracey Generating Station, a natural gas power plant.

28.2 – Take Exit 32 for USA Parkway; off to the right, across some low ridges, is the site of the Reno-Tahoe Industrial Center, which will contain the Tesla Gigafactory!

28.5 – Turn right at the stop sign onto NV-439, and immediately turn left onto a minor paved road that circles underneath the I-80 off-ramp.

28.8 – Turn right at the stop sign and cross the Truckee River.

29.6 – **Stop 2 (GPS coordinate: 39.566686°, -119.500112°): Pluvial–Lake Lahontan history and stratigraphy** Park in the dirt parking lot, and walk 330 ft (100 m) back east up the road to the road cut. The road cut exposes lacustrine sediments of pluvial Lake Lahontan. Here, we will introduce climatic and pluvial lake cycles in western Nevada and view layered lacustrine stratigraphy. Following this stop, drive back toward I-80.

30.4 – Turn left, pass underneath the I-80 off ramp, turn right at the stop sign at mile 30.6, and immediately turn right to merge onto I-80 East.

32.0 – On either side of the road are late Miocene basalt flows (~10 million years old) that may represent a remnant shield volcano.

33.2 – Lake Lahontan sediments are visible on the left.

36.2 – At the 2–3 o'clock position, the obvious white rock is a ~10-million-year-old diatomite mine.

38.5 – The colorful rocks on the left are 25–30-million-year-old ash-flow tuffs that filled paleovalleys; also visible for the next mile are Lake Lahontan sediments.

41.7 – Take exist 43 for Wadsworth/Pyramid Lake, turn left at the stop sign onto NV-427 toward Wadsworth, and pass underneath I-80.

43.2 – Entering Pyramid Lake fault zone, a major active right-lateral strike-slip fault in the northern Walker Lane.

43.4 – Turn left onto highway NV-447.

45.0 – Crossing Dodge Flat; Oligocene tuff is visible in front; prominent shorelines of pluvial Lake Lahontan are visible in the ridge to the right.

50.0 – On the right, Lake Lahontan highstand shoreline and lacustrine sediments are visible.

52.3 – Crossing strands of the right-lateral Pyramid Lake fault zone

53.0 – **Stop 3 (GPS coordinate: 39.749675°, -119.331970°): Overview of pluvial–Lake Lahontan highstand shoreline and deep-water stratigraphy** At this stop we will discuss the evidence for older lakes based on stratigraphic relations exposed in the bluffs on either side of the Truckee River.

55.0 – First view of Pyramid Lake, the terminus of the Truckee River

56.0 – Turn left onto a dirt road and pass through a gate in the barbed-wire fence; the road here is slightly overgrown but easily manageable in a 2-wheel-drive car.

56.3 – Veer left onto a dirt road

57.4 – **Stop 4 (GPS coordinate: 39.773547°, -119.367175°): Northern Walker Lane and Pyramid Lake fault zone** At this stop we will discuss the tectonic history of the Pyramid Lake fault and its role in accommodating part of the relative motion between the Pacific and North American plates.

58.5 – Head back to the main paved road; remember to veer right just past the corral

58.8 – Turn left on the main highway and head toward Pyramid Lake.

61.4 – Turn left onto highway NV-446

64.5 – The alignment of trees off to the left shows the trace of the Pyramid Lake fault; there are also some tufa deposits along the fault trace.

72.9 – Turn right onto dirt road toward the large tufa tower

73.1 – **Stop 5 (39.9904567°, -119.536755°): Tufa formations of Pyramid Lake and Holocene lake level history** We'll have lunch here; explore the tufa tower and discuss the various types of tufa, many of which are present along the beach directly beneath the parking area. We will also discuss the various highstands of the lake through the Holocene.

73.2 – Turn right back onto the paved highway

75.0 – Turn left onto highway NV-445 toward Sparks

75.8 – **Viewpoint (GPS coordinate: 39.902408°, -119.565833°):** There is a great viewpoint on the left here that provides a fantastic look at Pyramid Lake, Anaho Island, "the pyramid" tufa tower, and the Lake Range to the east. Although not an official field trip stop, the viewpoint provides a great opportunity to take a photograph.

76.0 – Nice view of Mullen Pass; the jagged ridges are ~23-million-year-old volcanic necks, or possible remnants of a caldera.

79.8 – Rhyolite domes are visible off to the right and left.

81.0 – Turn right on a dirt road and drive over a cattle guard; turn right after 0.1 miles, and then in 0.1 miles stay right at fork.

81.5 – Veer left at fork, and at mile 81.8 keep right at the fork.

82.4 – Keep right/straight at this intersection.

82.9 – **Stop 6 (GPS coordinate: 39.887703°, -119.632793°): Diatomite fossil hunting** Here we will do some fossil hunting! The ~15-million-year-old diatomite exposed in trenches contains numerous leaf fossils. When finished, turn back and drive back the way we came.

83.4 – Turn right down a dirt road, keep straight at the next intersection, and keep left at mile 83.8.

83.9 – **Stop 7 (GPS coordinate: 39.886234°, -119.644839°): Rock collecting in ash-flow tuff deposits** Keep left and turn right across the drainage to park for this rock collecting stop in the ash-flow tuff. We will hike up the rough road for about 1/2 mile. When finished, we'll turn around and head back toward the main paved road.

84.1 – Stay straight on the dirt road; at mile 84.2 veer right at the fork, and turn left onto dirt road at mile 84.4.

85.6 – Veer left toward paved highway.

85.8 – Turn right after crossing a cattle guard onto the paved highway.

88.0 – Here is the Warm Springs Valley fault; it extends up the valley to your 4 o'clock.

97.5 – The Spanish Springs Valley fault zone is off to the right along the base of the hills.

108.6 – Turn right onto McCarran Blvd.

110.4 – Turn right onto US-395 North.

111.8 – Take Exit 71 for Parr Blvd./Dandini Blvd.

112.3 – Turn right at stop sign onto Dandini Blvd. and next veer right onto Raggio Pkwy.

112.7 – Turn left and end at the Gold Building.

FIELD STOP DESCRIPTIONS

Stop 1. Washington Hill rhyolite dome and McClellan Peak basalt

At this stop we can observe two distinctly different types of volcanic deposits—so-called "bimodal volcanism": high-silica content rhyolite (lighter colored) and low-silica content basalt (darker colored). This juxtaposition of these two types of volcanic rocks tells us something about the tectonic activities in western Nevada since the middle-to-late Miocene. Bimodal volcanism is commonly associated with regional extension. Rhyolitic and basaltic volcanic rocks along I-80 have ages ranging from 10 to 1 million years old, which provides indirect evidence that extension has been affecting this region since ~10 million years ago.

The large hill to the south is the ~10-million-year-old Washington Hill rhyolite dome (figure 4). The rhyolite is light gray and contains very sparse of plagioclase feldspar and biotite phenocrysts in a glassy groundmass. Construction aggregate is mined from Washington Hill (figure 4).

Figure 4. Google Earth view of the Washington Hill rhyolite dome showing the extensive aggregate mining operation.

The darker rock capping many of the hills and ridges directly adjacent to the canyon is the McClellan Peak basalt. These ~1.4-million-year-old basalt flows are up to 5 m (16 ft) thick. The fine-grained volcanic rock is vesicular (has holes that probably formed from trapped air bubbles) and contains phenocrysts of olivine, plagioclase feldspar, and pyroxene. The basalt flows probably dammed the Truckee River for some time, possibly reversing its flow direction or forming minor lakes, before the river could erode through these deposits. Remnants of this widespread lava flow are presently observed on both sides of the Truckee River.

Stop 2. Pluvial–Lake Lahontan history and stratigraphy

At this stop, we will see some of the westernmost deposits of pluvial Lake Lahontan in the Truckee River canyon. These deposits are associated with the Sehoo highstand of the lake. Shoreline features will become more prevalent as the trip heads farther east and north into the Lake Lahontan and Pyramid Lake basins, respectively.

Lake Lahontan is a pluvial lake that formed within the western part of the Great Basin, occupying a vast area during the middle to late Pleistocene (figure 5). A pluvial lake is one that has had considerable fluctuations in water levels primarily due to climatic changes and fluctuations in precipitation and evaporation rates. Lake Lahontan formed at a time when regional climatic conditions were much different than they are today. Precipitation in the Great Basin region was at a much higher level, and evaporation rates were much lower than today. At its highstand, Lake Lahontan was the second largest pluvial lake in the northern hemisphere and was 920 ft (281 m) deep (compared to 350 ft [106 m] in 2004), covering 8,800 square miles (22,800 km^2), a surface area slightly larger than present-day Lake Ontario.

At this stop, we will examine thinly bedded deposits associated with the lake (figure 6). As the trip progresses, we will observe evidence for the highstand shoreline in many places. Shoreline features typical of pluvial lakes include constructional beach ridges, sand spits, tombolos, pocket barriers, deltas, and beach complexes, as well as erosional features such as cliffed headlands and bedrock notches (figure 7). Adams and Wesnousky (1998) conducted detailed mapping of geomorphic features related to the lake in the Jessup embayment in the Carson Sink, southeast of Pyramid Lake. Based on this work, they determined that the lake reached its latest Pleistocene highstand elevation of 4,400 ft (1338.5 m) and receded from that elevation immediately prior to 13,070 ± 60 yr before present. The age is based on radiocarbon dating of a camel bone preserved in high shoreline deposits.

We will talk more about older cycles of Lake Lahontan (stop 3) and several latest Pleistocene and Holocene lake level fluctuations of Pyramid Lake (stop 5) later in the trip.

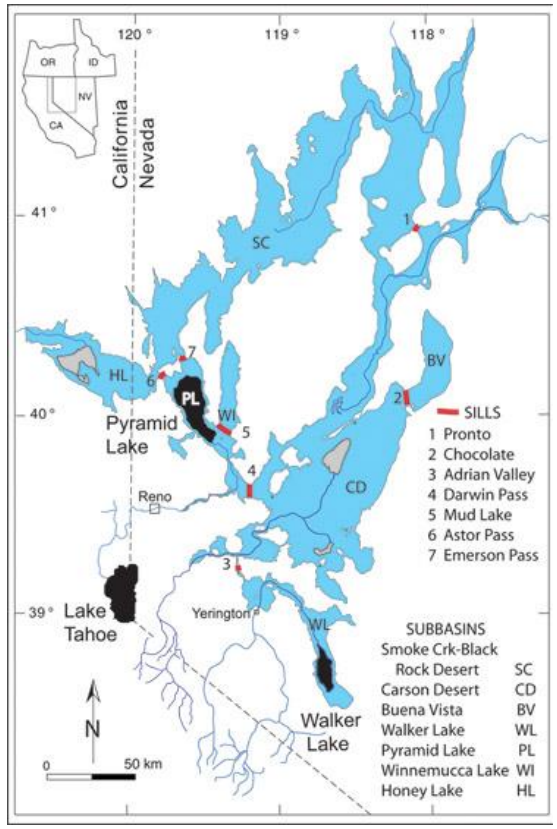


Figure 5. Pluvial Lake Lahontan at its highstand about 15,000 years ago (blue area). Black areas show existing lakes and gray areas show ephemeral lakes and sinks. Red lines indicate overflow points (sills) between subbasins.

Stop 3. Overview of pluvial–Lake Lahontan highstand shoreline and deep water stratigraphy

The white bluffs across the river from stop 3 are deep water clays, silty clays, and minor fine sand deposits associated with the Sehoo highstand of paleo Lake Lahontan (figure 8). Stratigraphic studies of the bluff sediments between stop 3 and Wadsworth to the south reveal a complex history of lake filling and subsequent desiccation.

The sedimentary record of the Truckee River includes a complex mix of fluvial, deltaic, and lacustrine environments. A good summary of the stratigraphic details is contained in Smoot (1993), some of which is reproduced here. There are at least 10 mappable units of lacustrine clay and silty clay that represent periods of lake deposition exposed in the canyon (figure 9). The thickest sequence of lacustrine

Figure 6. Thinly bedded lacustrine stratigraphy exposed at stop 2. Photo by Ken Adams.

silt and clay includes the Wadsworth tephra (~160–201 thousand years ago) and characteristically consists of deep lake clays grading upward into stacked Gilbert deltas that were deposited between about 350 to 120 thousand years ago. These deposits are associated with three deep-lake cycles culminating in the Eetza highstand, which occurred during marine Oxygen Isotope Stage 6 (~130–180 thousand years ago). The deposits of the Eetza highstand are capped by a regionally extensive soil known as the Churchill Geosol (Wyemaha Alloformation), which developed in subaerially exposed lacustrine, fluvial, and alluvial sediments. The soil is up to several meters thick in places and represents tens of thousands of years of soil formation. The Churchill Geosol is buried by deep, moderate, and shallow water lake deposits associated with the Sehoo Alloformation, which spans the last ~70 thousand years (marine Oxygen isotope stages 4 and 2). As mentioned earlier, the highstand shoreline deposited by the lake was abandoned after the lake desiccated around 13 thousand years ago.

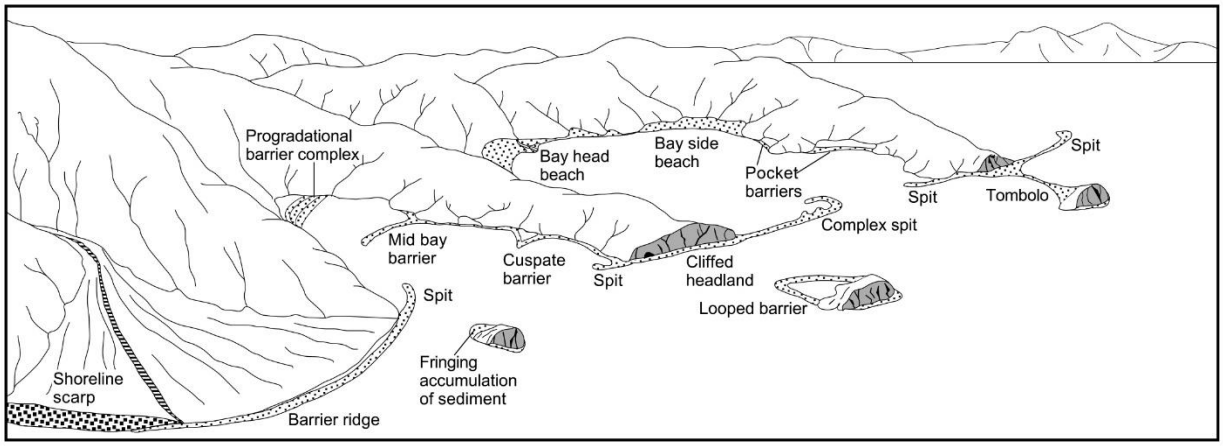


Figure 7. Typical shoreline features formed by pluvial lake processes. These types of features can be easily recognized throughout the Lake Lahontan basin including the Pyramid Lake subbasin. Taken from Adams and Wesnousky (1998).

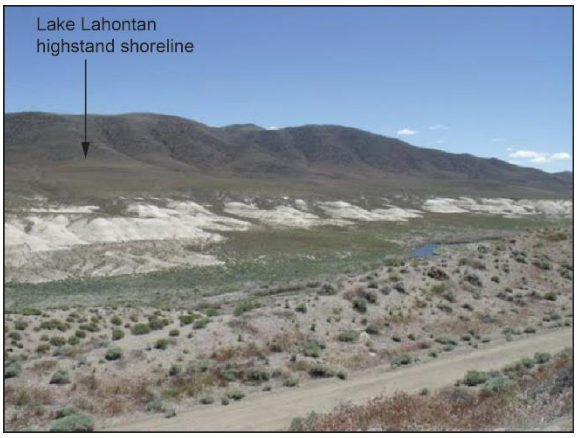


Figure 8. View of the Lake Lahontan highstand shoreline and deep water deposits from stop 3.

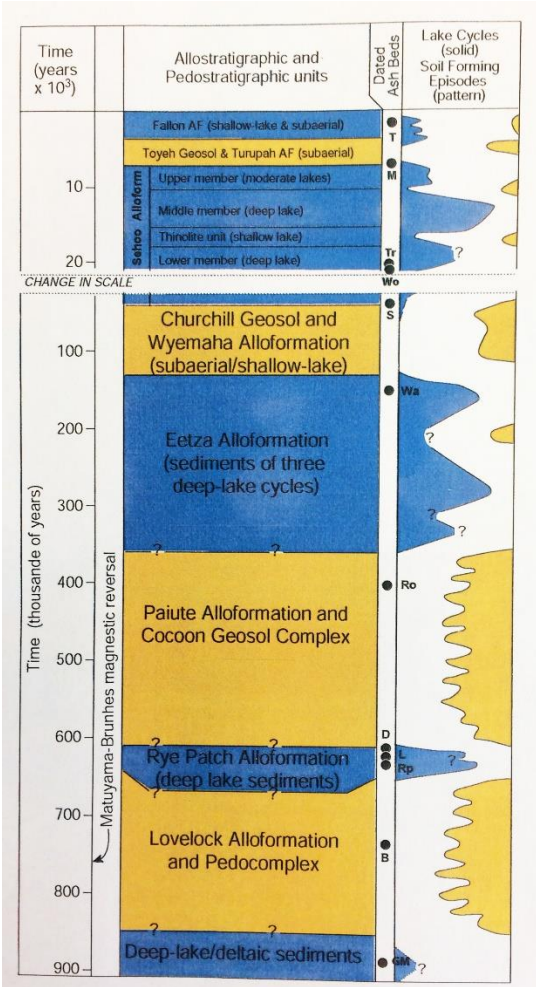


Figure 9. Stratigraphic column showing lacustrine deposits of various cycles of pluvial Lake Lahontan (blue) and soils developed during inter-lacustrinal periods (yellow). Modified from Morrison (1991).

Stop 4. Northern Walker Lane and Pyramid Lake fault zone

At stop 4, we will park at a drainage divide along the Pyramid Lake fault zone above the highstand shoreline of Lake Lahontan (figure 10). South of the drainage divide, the fault extends along a prominent linear valley. North of the divide, the fault laterally offsets the highstand and recessional shorelines of pluvial Lake Lahontan and is also associated with several uphill facing scarps in Holocene alluvial-fan deposits. Farther north, the fault is coincident with several springs (dark green grassy zones) and alignments of trees.

At the latitude of Pyramid Lake, approximately 15–25% of the Pacific–North American plate boundary strain is accommodated east of the Sierra Nevada through a combination of normal oblique (dextral) slip on the Sierra Nevada frontal fault system and dextral slip along faults in the northern Walker Lane. Geodetic studies indicate that around 7–10 mm/yr of dextral shear is distributed across the northern Walker Lane (Hammond et al., 2011). The majority of this slip is accommodated along the left-stepping Pyramid Lake, Honey Lake, Warm Springs Valley, and Mohawk Valley faults. Late Pleistocene slip rate estimates for the Pyramid Lake fault range between ~2.6 ± 0.3 mm/yr and 1.0 ± 0.3 mm/yr (Briggs et al., 2004; Angster et al., 2014). Geologic studies indicate a Holocene slip rate of ~1–2 mm/yr for the Honey Lake fault (Turner et al., 2008; Wills and Borchardt, 1993) and a late Quaternary slip rate of 1.8–2.4 mm/yr for the Warm Springs Valley fault (Gold et al., 2013).

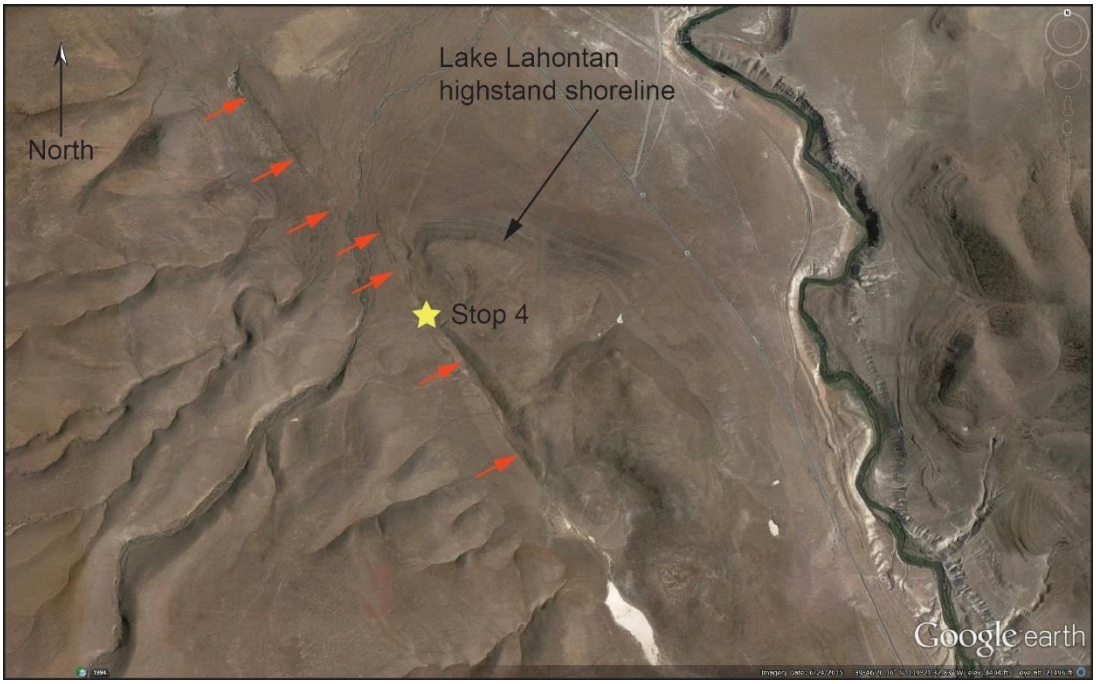


Figure 10. Google Earth satellite image of the Pyramid Lake fault zone and shorelines of pluvial Lake Lahontan at Stop 4.

The Pyramid Lake fault zone is a long (28 miles/45 km), nearly continuous northwest trending dextral fault zone that extends from about 9 miles (15 km) south of Fernley northwest to the southern margin of Pyramid Lake (figure 11). North of Pyramid Lake, the fault system splits into a range front normal fault that bounds the southwestern side of the Lake Range and a normal oblique dextral fault that continues through Pyramid Lake. South of the lake, the fault is associated with prominent geomorphic surface features indicative of active deformation including sag ponds, en echelon left-stepping surface scarps, elongate depressions, offset stream channels, and vegetation lineaments.

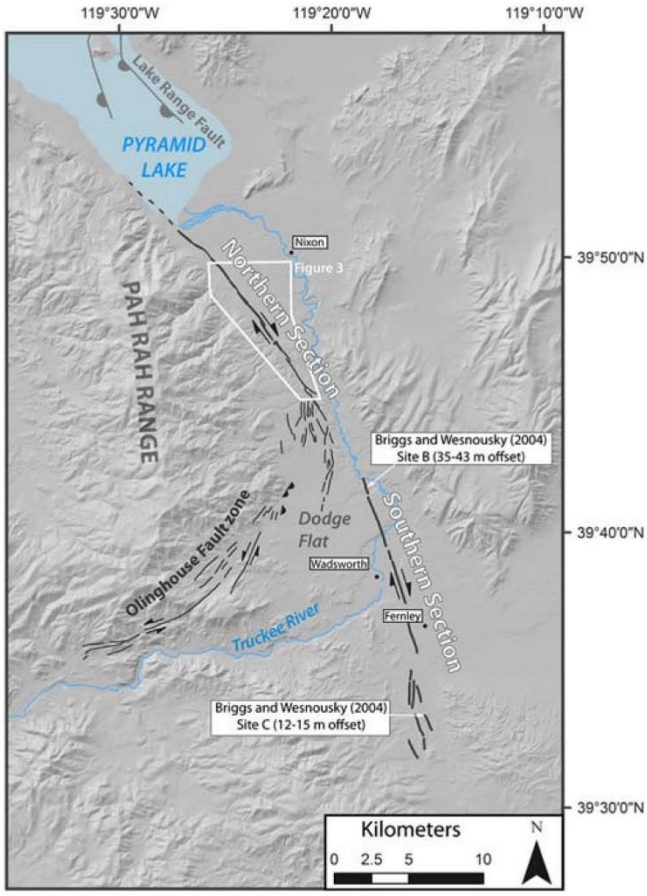


Figure 11. Digital elevation model of the Pyramid Lake fault zone showing areas of previous paleoseismic studies. White box outlines area of detailed studies by Angster et al. (2016).

The Pyramid Lake fault zone is capable of producing large magnitude damaging earthquakes. Several recent paleoseismic studies have focused on better characterizing the timing of past earthquakes and the rate of fault movement. These studies have contributed valuable information to the assessment of seismic hazards in western Nevada. Briggs et al. (2004) conducted geomorphic mapping and trenching along the fault and determined that geomorphic features preserved in post–Lake Lahontan (~15,500 calibrated years before present) surfaces indicate that the fault has accommodated at least 2.6 ± 0.3 mm/yr of slip during the late Pleistocene. Assessment of trench exposures indicates that the fault has generated at least four earthquakes since the desiccation of Lake Lahontan and that the most recent earthquake occurred after 1,705 ± 175 calibrated years before present.

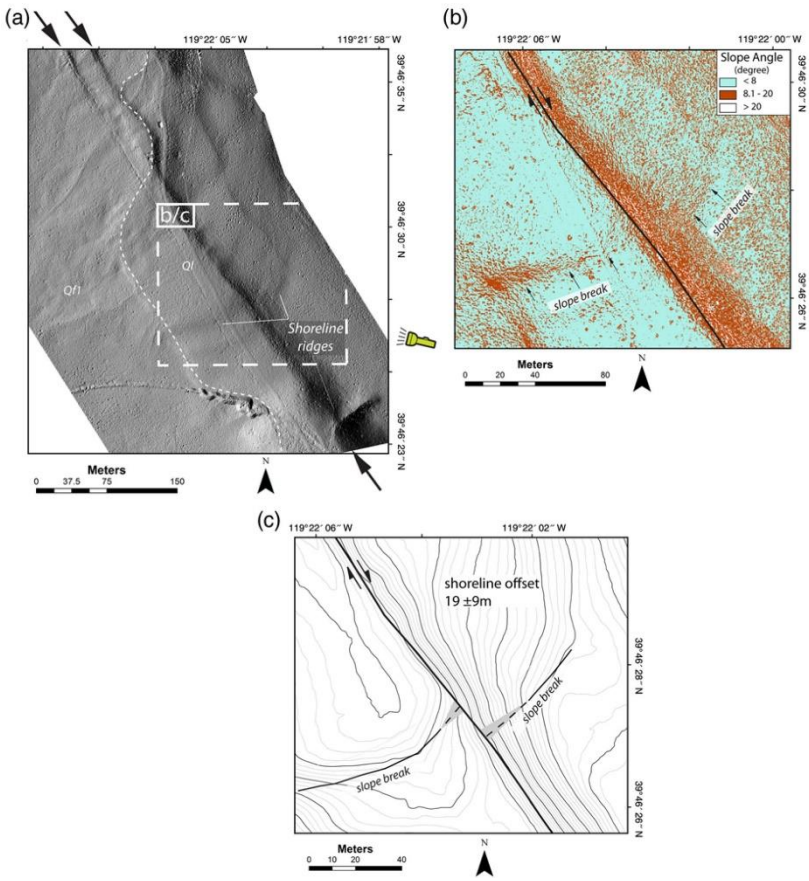


Figure 12. (a) Hillshade map showing uphill facing scarp and offset shoreline ridges. (b) Slope map defining slope break (arrows) on northwest face of the shoreline ridge. (c) Contour map showing the projection of the slope break to the fault trace (shaded areas). Taken from Angster et al. (2016).

Angster et al. (2016) used Quaternary mapping and a camera-mounted unmanned aerial vehicle (UAV) to develop high-resolution digital elevation models of geomorphic features offset across the fault (figure 12). The resulting models resulted in more accurate assessments of the amount of offset and a refinement of the slip rate. Based on the offset measurements and the ages of displaced features interpreted from mapping studies of Lake Lahontan sediments, Angster et al. (2016) estimated the slip rate to be between 0.5 and 1.6 mm/yr. Although slightly slower than the Briggs et al (2004) estimate, both studies are relatively consistent with geodetic measures of strain accumulation.

Geologic studies have placed constraints on the total amount of dextral displacement across the northern Walker Lane and the Pyramid Lake fault zone (Faulds et al., 2005). Well-defined axes and/or margins of Oligocene age paleovalleys (about 23 to 30 million years old), stretching from the Nightingale Range in western Nevada to the Diamond Mountains in northeastern California, provide piercing lines with which to estimate offset across the major strike-slip faults in the region (figure 13). The composition and age of rock units demonstrate that all segments of this paleovalley system contain a similar, westward-thinning sequence of 31–23-million-year-old ash-flow tuffs. These tuffs were erupted from calderas in central Nevada. The tuffs flowed westward down major paleovalleys to the Pacific Ocean, which at that time was located in the Sacramento area. The westward thinning of tuffs reflects greater distance from source calderas in central Nevada. The Sierra Nevada and accompanying rain shadow that is responsible for the arid climate in Nevada formed much later in time.

For the Pyramid Lake fault, offsets of the paleovalley suggest up to ~10 km (6.2 miles) of displacement. East of the Pyramid Lake fault, the Nightingale Range contains a WSW-trending, ~10-km-wide paleovalley with an abrupt northern margin, where the entire >700-m-thick (~2,300 ft) sequence of 11 tuffs pinches out. The southern Lake Range, however, contains only a thin veneer (<30 m thick or about 100 ft) of Oligocene tuff, indicating that the westward continuation of the paleovalley projects south of the range. West of the Pyramid Lake fault in the Virginia Mountains, the northern part of a WSW-trending paleovalley contains a 600-m-thick (1968 ft) sequence of 15 ash-flow tuffs. Nearly identical tuff sequences in the Nightingale Range and Virginia Mountains indicate correlation of the respective paleovalley segments. On the basis of the westerly trend, this paleovalley has been offset 5 to 10 km (about 3 to 6.2 miles) in a right-lateral sense across the Pyramid Lake fault.

All of this offset has occurred since about 5 million years ago, which suggests long-term slip rates on the order of 1 to 2 mm/year (less than 0.1 inches per year). Collectively, however, the entire system of right-lateral faults in the region (Pyramid Lake, Warm Springs, Honey Lake, and Mohawk Valley faults) has accommodated about 30 km (~20 miles) of offset, suggesting long-term strain rates up to about 6 mm/year (up to about 0.3 inches/year). However, on the basis of GPS geodetic stations, the current regional strain rate is greater, about 10 mm/year (or nearly 0.4 inches/year), suggesting that activity on this fault system has been increasing through time.

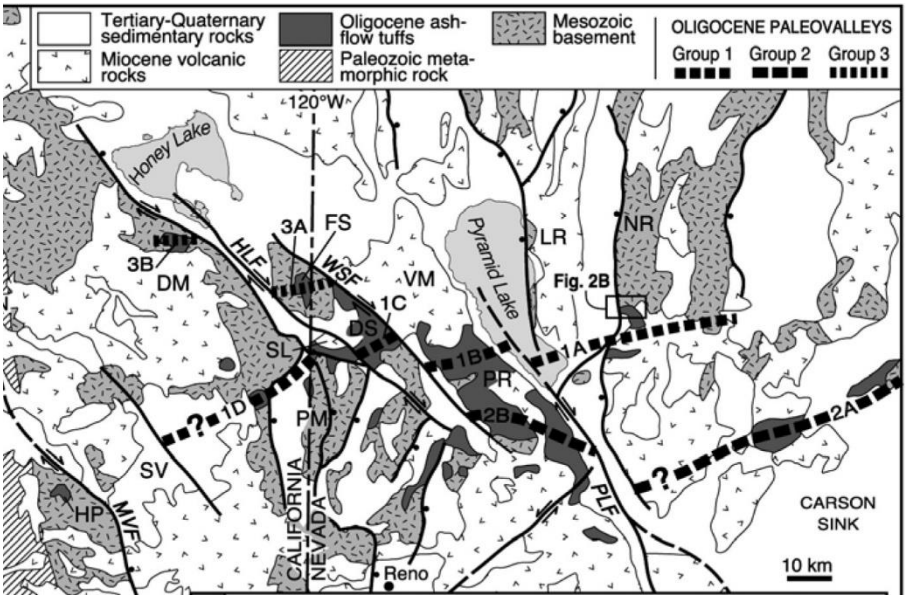


Figure 13. Northern Walker Lane showing left-stepping, NW-striking dextral faults and offset paleovalley axes. Paleovalleys are grouped into three sets. Individual segments in each set are inferred to represent an originally continuous paleovalley. Taken from Faulds et al. (2005).

Stop 5. Tufa formations of Pyramid Lake and late Pleistocene/Holocene lake level history

The following description of tufa formations at Pyramid Lake is modified from USGS (2004). Pyramid Lake is the site of some of the Earth's most spectacular tufa deposits. Tufa is a rock composed of calcium carbonate ($CaCO_3$) that forms at the mouth of a spring, from lake water, or from a mixture of spring and lake water. The explorer John C. Fremont (1845) wrote about the tufas during his 1843–44 expedition and named the lake after the pyramidal-shaped island that lies along the east shore of the lake. The Paiute name for the island is Wono, meaning cone-shaped basket. The Paiute name for the lake is Cui-Ui Panunadu, meaning fish in standing water.

Most of the tufas formed between 26,000 and 13,000 years ago when the climate was much wetter, and Pyramid Lake was joined to lakes in nearby subbasins. Tufas in the Pyramid Lake subbasin were first mentioned in scientific literature by Fremont (1845), who erroneously believed they had formed above water. Tufa mounds formed when springs discharged from the bottom of Pyramid Lake, supplying calcium that combined with carbonate dissolved in lake water to form the mounds. The thickest tufa deposits formed near lake-bottom sites of ground water discharge and at overflow elevations where the lake was held at near-constant levels for long periods of time.

Russell (1885) was the first to suggest that there were three tufa varieties, including lithoid (dense), thinolitic (crystalline) and dendritic (branching) (figures 14.1, 14.2, and 14.3). Two other varieties have been noted in the Pyramid Lake area: a fine-grained carbonate that cements sand and gravel forming beachrock (figure 14.4) and a thin white porous carbonate that coats the outer surfaces of older tufas (figure 14.5).

Tufa varieties combine to become tufa forms. Common forms include: tufa pillows, composed of branching tufa and dense tufa nodules; tufa tubes, composed of dense or branching varieties of tufa that sometimes surround a thinolitic crystal mesh; tufa sheets and drapes, which are primarily composed of branching tufa; and tufa spheres or barrels, commonly composed of one or more layers of thinolitic crystals. In some situations, tufa forms combine to create tufa megaforms, such as tufa mounds and tufa reefs (figure 14.6).

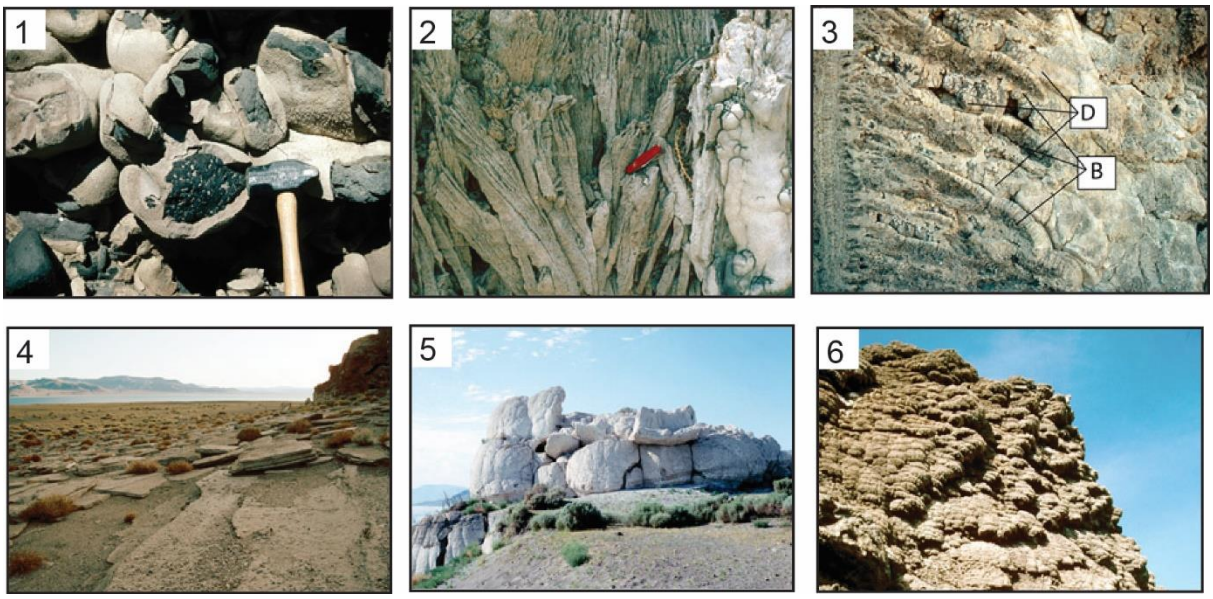


Figure 14. (1) Dense tufa coating volcanic cobbles. (2) Thinolite crystals. (3) Tufa pillows composed of branching tufa (B) and dense (D) tufa pendants and nodules. (4) Layers of tufa coated beachrock Tufa reef. (5) (6) tufa reef.

Tufas form in lake water, and their vertical growth is limited by lake level. In the Pyramid Lake subbasin, the elevations of the tops of many tufa mounds correspond to elevations of intersubbasin overflow points, or sills. When the level of Pyramid Lake was held constant by overflow to an adjacent subbasin, erosion of tufa and sediment occurred at and slightly above the overflow level, and deposition of tufa occurred below the overflow level. Terraces were produced by both erosional and constructional processes. In addition, many other reef-like tufa deposits formed on rocky headland areas when the level of Pyramid Lake was kept relatively constant by overflow to adjacent lake subbasins.

Many of the tufas around Pyramid Lake have been dated using the radiocarbon method (Benson and others, 1995). The elevations and ages of the tufa allow us to construct a lake-level history for the last 35,000 years. The data indicate that Lake Lahontan rose sharply about 26,000 years ago and was maintained at about 4,150 ft (1,265 m) for the next 7,000 years by overflow to the Carson Desert. After a brief fall to less than 4,101 ft (1,250 m), Lake Lahontan rose rapidly to its highstand (4,390 ft/1,338.5 m) about 15,000 years ago and then fell rapidly between 14,000 and 13,000 years ago.

Recent research has better defined the latest Pleistocene and Holocene lake level history. Briggs et al. (2005) defined four distinct sets of constructional lacustrine shorelines in the vicinity of the mouth of the Truckee River, directly south of the modern Pyramid Lake (figure 15). Based on geomorphic mapping and radiocarbon dates of organic material incorporated in constructional beach ridges, Briggs et al. (2005) determined that a late Holocene transgression of the lake reached an elevation of 3,894 ft (1,187 m) at 3,595 ± 35 years before present and 3,920 ft (1,195 m) at 2,635 ± 40 years before present. This lake ultimately reached an elevation of 3,934 ft (1,199 m) and was fully integrated with the Winnemucca Lake subbasin to the east. During the latest Pleistocene, a lake filled the Pyramid Lake subbasin to 3,976 ft (1,212 m) at 10,820 ± 35 years before present and the suite of shorelines associated with this lake stand can be traced up to 4035 ft (1,230 m). This lake was fully integrated with the Winnemucca, Smoke Creek/Black Rock, and Honey Lake subbasins (Briggs et al., 2005).

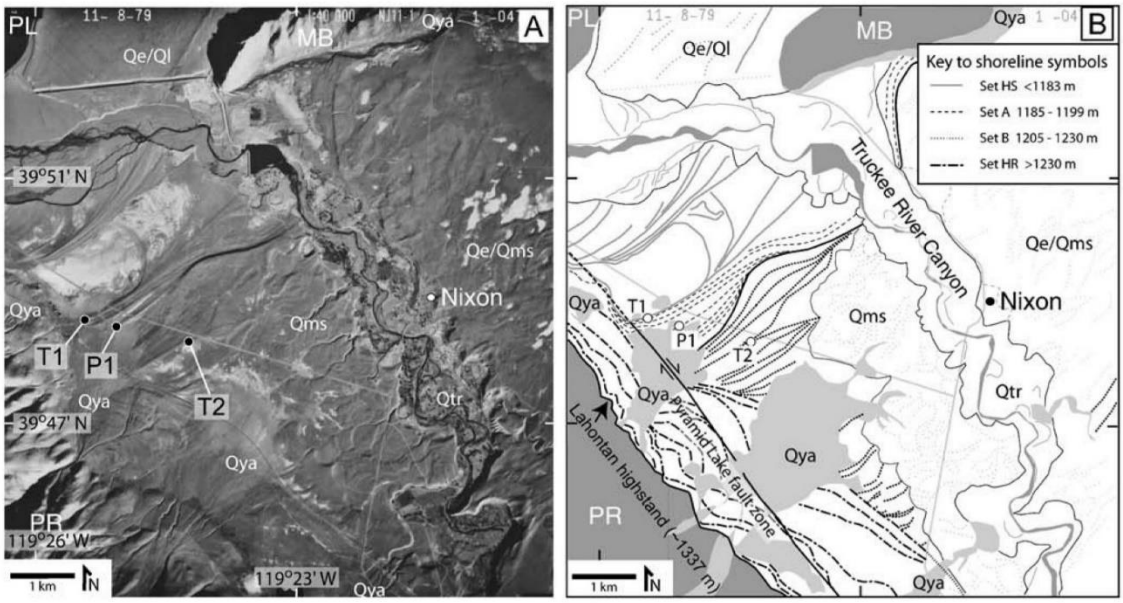


Figure 15. On the left is a vertical, low sun angle air photo showing shorelines in the Pyramid Lake subbasin. On the right is a generalized surficial geologic map of the same area showing the elevations of different lake levels and their associated beach berms. Taken from Briggs et al. (2005).

Stop 6. Diatomite fossil hunting

At this stop we will be examining shallow trenches of an old diatomite mine where we can find plant fossils. Diatomite is composed of tiny fossils of single-celled plants that thrived in the lake. Basalt rocks that are interbedded with the ancient diatomaceous lakebeds have been dated at 15.6 million years old. Leaf impressions are faint, white-on-white, so look carefully at broken rock surfaces to find them (figure 16).

The Pyramid Sequence fossil-plant site was discovered in 1951 by Dr. Ira La Rivers of the Biology Department, University of Nevada, Reno. Initial collections were made by Dr. Daniel I. Axelrod (then at the University of California, Los Angeles) in 1952. Later, in 1965 Professor Axelrod and Howard Schorn collected most of the recorded 1,414 fossils, of which the best preserved are now housed at the Museum of Paleontology, University of California, Berkeley. Professor Axelrod published a monograph on the fossil flora in 1992. Dr. Axelrod recognized a total of 41 different species at this site, of which five types of plants account for more than 80% of the total specimens. The five most abundant species, in order of their abundance, are: evergreen oak (Quercus), 27%; birch (Betula), 20%; 2 species of alder (Alnus), 28%; and maple (Acer), 6%. Dr. Axelrod's abundance counts tell us what types of fossil plants we are most likely to collect at this site.

Figure 16. Leaf impression in diatomite.

The fossil flora represented here are generally made up of six conifers and 25 hardwood species. The conifer species include pine, spruce, hemlock, fir, and swamp cypress. Both evergreen and deciduous hardwood trees and shrubs grew around the relatively small (a few square miles) lake. The abundant oaks, alders, birches, cottonwoods, willows, sycamore, rose, mountain-ash, and swamp cypress probably grew close to the lake and the streams coming into the lake. The species composition and physical nature of the leaves indicate that the fossil forest lived where the mean annual temperature was about 45°F and annual precipitation was about 35 inches evenly distributed throughout the year. It is quite striking to compare the estimated temperature and precipitation of the Pyramid fossil flora to that of the present-day Reno area, where the mean annual temperature is about 50°F and the annual precipitation of about 7.5 inches occurs mainly in the winter months. Recent work by Wolfe and others (1997) suggests that this region, and thus the ancient lake, stood at an elevation of about 3,000 m (~10,000 ft) in the middle Miocene (16.5 million years ago), and that the valleys have since dropped some 1,500 m (~5,000 ft), contributing to the change from the somewhat cooler Miocene mean annual temperatures to the present warmer mean annual temperature. The deposits of this Miocene lake should not be confused with a portion of Pleistocene Lake Lahontan, which partially filled Warm Springs Valley.

A large variety of volcanic rocks is exposed in the hills surrounding the fossil-leaf site. The massive cliff-forming rocks to the north of this site are flow domes of rhyolitic to dacitic composition. They are approximately 23.5 million years old.

Stop 7. Rock collecting in ash-flow tuff deposits

Here we can collect the ~25-million-year-old tuff of Chimney Springs. A tuff is a fragmental volcanic rock that was erupted violently into the air. Fragments commonly include pumice (frothy glass), ash (less than 2 mm-size fragments of glass, crystals, and rocks), and larger crystals and pieces of older rocks. If the fragments are still molten or hot, they will weld together to make an ignimbrite or welded ash-flow tuff, which can flow long distances. This rock contains fragments of flattened, dense pumice (compacted by the weight of the overlying tuff). Similar to many of the tuffs in this region, this one was erupted from a caldera in central Nevada about 25 million years ago. Crystals in this tuff include smoky quartz, bluish sanidine, biotite, and plagioclase.

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