Guide for the Earth Science Week Field Trip, October 20 or 21, 2012

Nevada Bureau of Mines and Geology Educational Series E-52

"Tuff All Over"
Exploring Faulted Volcanic Terrain in the Painted Hills, Virginia Mountains, West of Pyramid Lake

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National Earth Science Week (ESW) 2012 encourages people everywhere to explore the natural world and learn about the geosciences. The Nevada Bureau of Mines & Geology (NBMG) welcomes you to participate in its fifteenth annual Earth Science Week field trip. In keeping with the National ESW theme, "Discovering Careers in the Earth Science," this year's trip will focus on the Cenozoic geology of the Virginia Mountains, north of the Pyramid Highway and west of Pyramid Lake. You'll see how geologists use geologic maps to unravel the history of the area, assess earthquake hazards from evidence of recent faulting, and evaluate the potential for mineral resources. You'll be able to collect a variety of volcanic rocks, including several tuffs, and some diatomite, which has occasional leaf fossils.

We will **leave** from the Great Basin Science Sample and Records Library, the new building for information, publication sales, geologic and topographic maps, and geological samples of the Nevada Bureau of Mines and Geology, on the west side of the campus of the Desert Research Institute, **2175 Raggio Parkway**, Reno, NV 89512, **promptly at 8:00 a.m. each day**. Please meet there beginning at 7:30 a.m, if you would like a preview of the rocks that you'll be able to collect. This will be a tough trip, not only because we will be collecting several different tuffs and traveling on rough roads, but also because there are no bathroom facilities (but lots of bushes and rocks) along the way and because the last (optional) stop involves hiking about 2.8 miles, partly up a steep road. The trip is free and open to the public. Be sure to **bring your own four-wheel-drive vehicle (or arrange to ride in someone else's), lunch, sunscreen, hat, first-aid kit, and plenty of water**. Total distance traveled by vehicle is approximately 80 miles round trip. Some of the driving will be slow, so make sure you have plenty of gasoline. You can use this guide to take the trip on your own at another time, if you can't join us this year.

Stops will include the following:
Stop 1. Diatomite near Mullen Pass – with leaf fossils
Stop 2. Tuff of Mullen Pass – with black pumice fragments
Stop 3. Tuff of Chimney Spring – with white pumice fragments and colorful crystals
Stop 4. Incandescent Rocks Scenic Area: Nine Hill Tuff – with dark pumice fragments
Stop 5. Overlook of the Warm Springs Valley fault zone
Stop 6. 2.8-mile hike (round trip) to collect more samples of a variety of tuffs and petrified wood.

The information in this road log is taken largely from the listed references, particularly the geologic map of the Tule Peak Quadrangle by Faulds and others (2003). Please see the glossary for definitions of geological terms and for chemical formulas of common minerals that can be found on today's trip.

Items to have for the field trip:

Water – lots of it, a gallon per person
Food for lunch and snacks
Sunscreen and hat
First aid kit
Walking stick and gloves
Camera and binoculars
Bag, bucket, or box for samples
Insured vehicle with high clearance (you should have 4-wheel drive for this trip) and spare tire.

Road Log and GPS

This road log is in miles, starting at the Great Basin Science Sample and Records Library (fig. 1). Locations are given in longitude and latitude (degrees and decimal minutes) using the WGS 84 datum, the default in most global positioning system (GPS) instruments. For this location, GPS=39˚34.303´N, 119˚48.190´W. Set your trip odometer to zero (0.0). If you need to stop along the way, the maps that follow this road log should allow you to catch up. Figure 2 illustrates the overall route for the day. For those interested in using topographic maps, the main part of the field trip will be on the Fraser Flat, Sutcliffe, and Tule Peak 7.5' quadrangles.

Miles

0.0 Turn right (north) onto Raggio Parkway when leaving the parking lot (fig. 1).

0.1 Turn right (east) onto Dandini Boulevard (fig. 3). GPS=39˚34.391´N, 119˚48.225´W. The DRI and Truckee Meadow College campuses are located in an area of altered Miocene volcanic rocks (chiefly andesite) that were erupted when this area was part of the Cascades about 15 million years ago. The alteration is typical of many of the gold and silver deposits that have been an important part of Nevada's history. Acid-rich waters deposited metals in quartz veins, altered some of the volcanic rocks to form the silica knobs that dot the local landscape, and altered other volcanic rocks to montmorillonite, a clay mineral that swells when it gets wet and can cause problems with building and highway construction. Today we are in the midst of the biggest gold-mining boom in world, American, and Nevada history. Nevada produces more gold than any other state and, in recent years, about 7% of the world's gold.

1.4 Continue straight, across Clear Acre Lane/Sun Valley Boulevard, onto El Rancho Drive. GPS=39˚34.224´N, 119˚46.926´W.

2.8 Turn left (east) onto McCarran Boulevard. GPS=39˚33.434´N, 119˚46.751´W.

4.2 Turn left (north) onto Pyramid Highway (Fig. 3). GPS=39˚33.386´N, 119˚45.163´W.

4.8 The area to the left (west) is part of the Wedekind Mining District, which produced small volumes of gold in the late 1800s. This area also has numerous silica knobs surrounded by andesite that has been altered to montmorillonite.

9.0 Pass the turnoff (right, east) to Lazy 5 Park, where there are restrooms. GPS=39˚37.294´N, 119˚43.501´W.

10.0 Spanish Springs High School is visible near the base of the mountain on the left (west), where four inches of rainfall on June 20–21, 2002 triggered a flood and debris-laden mudslide that caused more than a million dollars' worth of damage. Detailed geologic mapping of the sediments on alluvial fans before building on them can help direct development to areas less susceptible to flooding and help design debris detention basins that work to prevent such damaging events.

12.0 The mining operation at base of the mountain to left is the Sha-Neva pit, a sand & gravel and crushed rock/aggregate facility that has been operated for many years by Martin Marietta Corporation. It mines Cretaceous granodiorite (an igneous rock similar to granite) for use in construction projects in the Reno-Sparks area. A range-front fault at the base of the mountain has crushed the rock and allowed it to weather into "DG" or "decomposed granite," which is also mined and sold for construction and landscape use.

18.6 The hills on the right are capped by west-dipping Oligocene ash-flow tuffs, volcanic rocks that are 25–30 million years old.

19.7 Pass the turnoff (left, northwest) for Winnemucca Ranch Road. Continue straight on Pyramid Highway. GPS=39˚46.134´N, 119˚41.119´W. Dogskin Mountain, the prominent peak at 10 o'clock (to the northwest), is composed mainly of gray and black speckled intrusive igneous rock called quartz monzodiorite. It is Cretaceous in age, similar to many of the rocks in the Sierra Nevada. For the next few miles, we will be crossing the Warm Springs Valley fault zone, one of many northwest-trending, right-lateral strike-slip faults that make up the Walker Lane, a zone approximately 100 km (60 mi) wide extending from Susanville, California, along the California-Nevada border, to as far south as Las Vegas. On the basis of GPS technology, which allows us to measure the actual movements of the Earth's crust in response to the movement of the underlying tectonic plates, we know that these northwest-striking faults accommodate approximately 20% of the strain between the Pacific and North American tectonic plates. Most of the tectonic strain is accommodated on the San Andreas and other faults near it in California, which parallel the right-lateral strike-slip faults of the Walker Lane. The rocks bordering such faults are being mapped in detail by NBMG geologists to better understand the history of slip along the faults, and movement of the ground is being measured by NBMG geodesists using state-of-the-art satellite technology.

21.2 On the right is the Wild Horse and Burro adoption facility operated by the U.S. Bureau of Land Management.

22.0 Entering Warm Springs (also known as Palomino) Valley. The brightly colored volcanic layers at 11 o'clock (to the north) are called the Painted Hills and Incandescent Rocks, which we will visit on Stop 4 today. Depending largely on the quantity and type of iron minerals present in the rocks, they are colored shades of red and pink (from hematite), orange and beige (from goethite), or cream and white (with little hematite or goethite).

24.9 Pass the turnoff (left, west) for Grass Valley Road. Continue straight on Pyramid Highway. GPS=39˚50.422´N, 119˚39.475´W. We'll return here on our way to Stop 4.

26.0 Pass the turnoff (left, west) to the shooting range. Continue straight on Pyramid Highway, but begin to slow down for our turnoff ahead.

26.8 Turn left (north) onto dirt road and over a cattleguard (figs. 4 and 5). GPS=39˚51.874´N, 119˚38.777´W.

27.0 Bear right at fork in a dirt road by gravel pit.

27.1 Bear right at fork in the dirt road.

27.3 Bear left at fork in the dirt road. GPS=39˚52.191´N, 119˚38.661´W.

27.6 Bear right at fork in the dirt road

28.0 At crest of hill, bear right at fork in the dirt road.

28.2 Bear right at fork in the dirt road.

28.8 **STOP 1**. Park on the left side of the road where white rock is visible. GPS=39˚53.246´N, 119˚37.957´W. Here we can collect diatomite, a white, low-density rock composed of microscopic fossils of diatoms, a type of algae. The rock, which locally contains impressions of leaves (fig. 6), is Miocene in age and probably formed in a lake between volcanic highlands.

Within 100 feet or so of the road you will find shallow trenches that have been dug to expose the plant-fossil-bearing horizon in the diatomite unit of the Pyramid Sequence. Basalts that are interbedded with the ancient diatomaceous lakebeds have been radiometrically dated at 15.6 million years old. Leaf impressions are faint, white-on-white, so look carefully at broken rock surfaces to find them. This 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 Axelrod (then at the University of California, Los Angeles) in 1952. Later, in 1965 Professor Axelrod and Howard Schorn collected and recorded 1,414 fossils from the site, the best of which are now housed at the Museum of Paleontology, University of California, Berkeley. Professor Axelrod published a monograph on the fossil flora in 1992 in which he recognized a total of 41 different species at this site. Of these, five types of plants account for more than 80% of the total specimens. They are, in order of abundance:

- alder (2 species)(Alnus), 28%
- evergreen oak (Quercus), 27%
- birch (Betula), 20%
- maple (Acer), 6%

Dr. Axelrod's abundance counts tell us what types of fossil plants we are most likely to collect at this site but they do not necessarily mean that those species were present in these percentages in the Miocene forest. Many factors determine which leaves or other plant remains are preserved, such as the distance the tree lived from the lake, the size and weight of the leaf, and the durability or fragility of the leaf. These and many other factors of the deposition, burial, and finally our finding the fossils determine the numerical abundance of species in a fossil flora.

The 41 fossil floras represented here include six conifers and 25 hardwood species. The conifers include pine, spruce, hemlock, fir, and swamp cypress. Both evergreen and deciduous hardwood trees and shrubs grew around the relatively small (probably 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 for these fossils 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. As we will learn at Stop 3, during middle Miocene time there was probably no mountain range like the Sierra Nevada to create a rain shadow like today in Nevada.

Recent work suggests that this region, and thus the ancient lake, stood at an elevation of about 10,000 feet in the middle Miocene, and that the valleys have since dropped some 5,000 feet, 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. In Garside and others (2003), the Lahontan deposits are on the valley floor and are described as: "tan to brown and gray sandy-clayey silts to clayey-silty sands, commonly with white salt-encrusted surfaces. The deposits are poorly to moderately sorted, weakly indurated to non-indurated, and are moderately to strongly horizontally stratified. The deposits generally have a smooth to hummocky surface with small coppice dunes and minor salt crusted flats; they are more than 1 m thick." The edges of these deposits may run into coarser shore, strand, and beach deposits.

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.

28.8 Continue straight ahead (north).
29.2 Turn right (east).
29.4 Turn right (southeast).

29.5 **STOP 2**. GPS=39˚53.542´N, 119˚37.502´W. Here we can collect the glassy lower tuff of Mullen Pass. 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 abundant fragments of flattened, dense pumice (compacted by the weight of the overlying tuff) that is black, like obsidian (Fig. 6), rather than white, the typical color of pumice. Unlike many of the tuffs that we will see at other stops, this one was probably erupted nearby. It is about 14 million years old, younger than most of the other volcanic rocks that we will see today. Crystals in the tuff include plagioclase, clinopyroxene, orthopyroxene, biotite, hornblende, and magnetite. Fragments of other volcanic rocks, including basaltic andesite, are abundant. The middle and upper tuffs of Mullen Pass are exposed immediately above the dark basal unit.

29.5 Head back along the same roads toward Stop 3 (northwest).
29.6 Turn left (west)
29.8 Cross road back to Stop 1, continue straight, into the canyon.

30.6 **STOP 3**. GPS=39˚53.579´N, 119˚38.604´W. Here we can collect the Tuff of Chimney Spring (fig. 8). This is one of several tuffs in the area that filled ancient valleys during the Oligocene Epoch. These tuffs were erupted from calderas in central Nevada and flowed all the way to the Pacific Ocean, which was in the area of the Central Valley of California at that time. That is, there was no mountain range like today's Sierra Nevada to keep rivers from reaching the ocean. Locating these valleys has been an important aspect of determining the displacement on major strike-slip faults in western Nevada, because the channels provide piercing points along the two sides of a fault. Details of how these paleovalleys have been used to determine the amount of offset on major faults in the area can be found in two papers by Faulds and others (2005a, b). The Warm Springs Valley fault zone, which we will cross after Stop 5, is one of these major strike-slip faults. Work by NBMG geologists has documented a long history of movement on the Warm Springs Valley fault zone, including several Holocene earthquakes, thereby adding to the earthquake hazard in the Reno-Sparks area.

The Tuff of Chimney Spring is characterized by abundant smoky quartz and adularescent (a milky bluish luster caused by microscopic chemical layering) sanidine crystals along with plagioclase, biotite, hornblende, and magnetite. It is usually pinkish gray to reddish brown or red. This tuff was formed from multiple eruptions, probably from a zoned magma chamber. White pumice fragments are common in the upper and lower parts of this unit, and fragments of other volcanic rocks, quartzite, and shale are common in the lower part. The rock is about 24.9 million years old.

30.6 Turn around and drive south, then east. Return to Pyramid Highway via Stop 1 (figs. 5 & 9).
31.3 Turn right (south) onto the dirt road that passes Stop 1.
33.5 Turn right (southwest) onto Pyramid Highway. GPS=39˚51.874´N, 119˚38.777´W.
35.4 Turn right (west) onto Grass Valley Road. GPS=39˚50.422´N, 119˚39.475´W. Follow Grass Valley Road as it then turns northwest and north.
38.2 Turn left (west) at the T intersection. GPS=39˚52.073´N, 119˚40.620´W.
40.0 Turn right (northeast) toward the Incandescent Rocks Scenic Area (figs. 10 and 11). GPS=39˚52.385´N, 119˚41.379´W.

41.2 **STOP 4**. Depending on the number of vehicles, we will probably need to park before the end of the road into this canyon (GPS=39˚53.149´N, 119˚40.503´W) and hike about 0.7 mile to the outcrop of Nine Hill Tuff (figs. 12, 13, and 14). GPS=39˚53.484´N, 119˚39.977´W at the outcrop beyond the end of the road.

The lower and upper tuffs of Incandescent Canyon and the Tuff of Chimney Spring are exposed in outcrops along this hike. These are more of the Oligocene tuffs that erupted from a caldera in central Nevada and flowed down an ancient valley to the Pacific Ocean.

The Nine Hill Tuff is a purplish to reddish-brown, moderately to densely welded, locally white to pale brown nonwelded tuff, which contains dark, flattened pumice fragments and a few crystals of sanidine, anorthoclase, plagioclase, quartz, biotite, clinopyroxene, and magnetite. It is about 25.1 million years old and underlies the Tuff of Chimney Spring.

The lower tuff of Incandescent Canyon overlies the Tuff of Chimney Spring, is a nonweleded gray or pinkish gray tuff, and contains crystals of sanidine, quartz, plagioclase, biotite, hornblende, magnetite, zircon, and apatite. The upper tuff of Incandescent Canyon is a nonwelded to poorly welded yellowish to pale-reddish-brown tuff with crystals of sanidine, plagioclase, biotite, magnetite, and apatite. It is about 24.7 million years old.

The ridge to the southeast of the parking area is underlain by a rhyolite dome. The rock is a flow-banded, light-gray, rock with abundant crystals of plagioclase, biotite, quartz, hornblende, and sanidine. It is about 23.5 million years old and locally intrudes and domes the older tuffs.

Other rocks that can be found in the streambed at Stop 4 include the Tuff of Chimney Spring, which is in fault contact with the Nine Hill Tuff near the end of the road, and andesite (with crystals of clinopyroxene, plagioclase, hornblende, and magnetite), which probably came from a nearby, now eroded and buried volcano. Bright green celadonite occurs in holes and along fractures in some of the andesite samples.

The tuffs in this area are tilted from their original nearly horizontal layering by numerous normal faults (formed by crustal extension), although some tuffs have steep dips as a result of having been deposited on the walls of canyons. This faulting causes the section of tuffs (Incandescent Canyon on top of Chimney Spring on top of Nine Hill) to be repeated as we move up the canyon, thereby enhancing the scenic views of multicolored tuffs. The normal faults are characteristic of the faults that dominate Nevada's basin and range topography. In this canyon, the faults strike dominantly northwest and dip southwest, whereas in much of Nevada, the major range-bounding faults strike north and dip either east or west. Many of the normal faults are active today and are an expression of much of the high earthquake hazard throughout the state. Northwest-striking right-lateral strike-slip faults, including the Warm Springs Valley fault zone, add to the earthquake hazard in western Nevada.

41.2 Retrace the route out of the Incandescent Rocks Scenic Area (fig. 15).

42.5 Turn right (northwest). GPS=39˚52.385´N, 119˚41.379´W.

For those not wanting to take the 2.8-mile hike at Stop 6 (figs. 16-21), you can continue on this road to Winnemucca Ranch Road (fig. 22) and then south back to the Pyramid Highway . You will cross the Warm Springs Valley fault zone again. Stop 5 is at the turnoff to Stop 6. If you decide to continue the field trip, follow the route a below:

43.2 Cross the north end of the runway for the airport/glider port. Continue northwest on the dirt road.

43.9 **STOP 5**. Overlook of the Warm Springs Valley fault zone and turnoff to Stop 6 (fig. 22). GPS=39˚52.832´N, 119˚42.820´W. A prominent hill in the middle of the valley, west of here, contains late Miocene to Pleistocene conglomerate, sandstone, and ash beds that are moderately tilted (38˚), probably by the same compressive forces that caused this hill to be pushed up along a segment of the Warm Springs Valley fault zone.

43.9 Turn right (northeast) toward Stop 6 (fig. 15).

45.3 Turn right (northeast) and park (fig. 16). GPS=39˚53.805´N, 119˚42.020´W. There is limited parking and the road worsens farther up the canyon. From here we will hike on roads approximately 1.1 mile to Stop 6a and another 0.3 mile to Stop 6b. On the hike, turn right (east) after 0.7 mile (GPS=39˚53.950´N, 119˚41.421´W). You should be able to find samples of Nine Hill Tuff and Tuff of Chimney Spring along the way; you can retrieve your best specimens along the road on the way back down the hill.

STOP 6a. The Delongchamps Mine (figs. 17 and 18) is one of several mines that produced small amounts of uranium in the Painted Hills during the 1950s and 1960s (Castor and others, 1996). GPS=39˚53.772´N, 119˚41.281´W. The Delongchamps and the Red Bluff, which will be visited in the next stop, were reported to have shipped "small tonnages of ore" between 1955 and 1961 and then 200 tons of ore grading 0.23% U_3O_8 (911 lbs. U_3O_8) in 1966 (Garside and Davis, 2006). The Delongchamps and the Red Bluff together have over 300 feet of underground workings (Garside, 1973; Garside and Davis, 2006). The old mines are dangerous – with hard-to-see drop-offs inside the adits, so **STAY OUT and STAY ALIVE**. Interesting minerals can be found on the dumps, including smoky quartz in the Tuff of Chimney Spring, opal (some of which is uraniferous), chalcedony, cristobalite, meta-autunite, sabugalite, hematite (also locally uraniferous), kaolinite, montmorillonite, manganese oxides, and possibly phosphuranylite, uraninite, uranophane, and uranospinite. The tuff is bleached (iron coloration removed) and locally silicified (quartz added) near uranium mineralization, and the quartz crystals in the tuff are nearly black due to alpha radiation over time. Rhyolites are in general enriched in uranium relative to other typical igneous rocks.

STOP 6b. Farther along the road and around the hill from Stop 5a is the Red Bluff Adit, another small uranium mine (figs. 19 and 20). GPS=39˚53.887´N, 119˚41.149´W. Here the Tuff of Chimney Spring was intruded by an andesite dike, presumably of Miocene age. The dike also occurs at the Delongchamps Mine. It strikes generally northeast and dips 65˚ to 70˚ northwest. Uranium minerals occur as pods, stringers, and encrustations along fractures, primarily in the tuff. North of the adit are outcrops of a tuffaceous debris flow with fragments of andesite or basalt, large pieces of petrified wood (fig. 21), and charcoal. Opal occurs along fractures in the Tuff of Chimney Spring, and uranium mineralization is predominantly in the tuff near the contacts with the dike. Some of opal in this area fluoresces bright green in short-wave ultraviolet light as a result of small amounts of U^{6+} in the opal. Most yellow uranium minerals also fluoresce. In the late 1970s, U.S. Mining and Exploration owned the claims covering the Red Bluff area. Calculations from a drilling and sampling program indicated a uranium deposit containing 100,000 tons of ore averaging 0.24% U_3O_8 with a cut-off grade of 0.1%. However, uranium prices fell about that time making the deposit uneconomical to mine. In 1984, the area was sampled for gold and silver, but the reported values did "not exceed typical crustal abundances" (Hendrickson, 1991).

The uranium deposits of the Painted Hills are considered part of the Pyramid Mining District. Most of the mining and exploration activity in the district was south of the Pyramid Highway in the hills south of Stop 1. Small amounts of copper, lead, zinc, and silver were recovered from the mines in that area in the late 1800s. Mining claims were reportedly staked there as far back as 1863, but the district was organized in 1876. The town of Pyramid City was laid out in 1876 on the flat and had a post office briefly in 1879. Most of the production occurred prior to 1880, with the Jones-Kincaid Mine alone allegedly producing about $260,000, but the records are largely missing. Post-1880 records are also incomplete with about $95,000 of production reported for 1881 through 1952 (Bonham, 1969; Carlson, 1974; Tingley, 1998; Garside and others, 2003). Ores were probably related to the volcanic center there, with which the rhyolite domes are associated.

45.3 Return to the vehicles and back to Reno via Winnemucca Ranch Road (fig. 22).
46.7 Turn right (northwest) at Stop 5. GPS=39˚52.832´N, 119˚42.820´W.

48.0 Turn sharply to the left (south) onto Winnemucca Ranch Road. GPS=39˚53.233´N, 119˚44.108´W.

50.4 Continue straight on Winnemucca Ranch Road. GPS=39˚51.224´N, 119˚43.425´W. The green (depending on the time of year) area being passed on the left contains several small warm springs. The springs are noted as "hot" in Garside and Schilling (1979), and drillers' logs at the Nevada Division of Water Resources for domestic wells drilled to between 200 and 620 feet within a mile of these springs recorded temperatures of between 90 and 130˚F. These springs are probably along and east of a northwest-southeast trending basin bounding fault (Garside and others, 2003) separate from the Warms Springs Valley fault zone, which is about 1.2 miles to the northeast (fig. 22). The logs for domestic wells drilled in the area of the Warms Springs Valley fault zone commonly record temperatures as being "cool" or "cold." From the 1990s through the early 2000s several attempts were made to start an alligator farm using warm water from wells in this area (Dowd, 2003).

56.7 Turn right onto Pyramid Highway. GPS=39˚46.134´N, 119˚41.119´W. From here it's 19.7 miles back to the Great Basin Science Sample and Records Library. We hope you enjoyed the trip!

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GLOSSARY

Geologic Time Scale for This Area

Era	Period	Epoch	
Cenozoic	**Quaternary**	**Holocene**:	11,700 years ago to present
		Pleistocene:	2.6 million to 11,700 years ago.
	Tertiary	**Pliocene**:	5.3 million to 2.6 million years ago
		Miocene:	23.0 to 5.3 million years ago
		Oligocene:	33.9 to 23.0 million years ago
		Eocene:	55.8 to 33.9 million years ago
		Paleocene:	65.5 to 55.8 million years ago
Mesozoic	**Cretaceous**		145 to 65.5 million years ago
	Jurassic		201 to 145 million years ago
	Triassic		251 to 201 million years ago

Minerals and their Chemical Formulas

Anorthoclase, a feldspar solid solution dominantly between the end members potassium feldspar, $KAlSi_3O_8$, and albite, $NaAlSi_3O_8$, with lesser amounts of anorthite, $CaAl_2Si_2O_8$, clear to white; with cleavage

Apatite, $Ca_5(PO_4)_3(OH,F)$, occurs as small (less than 1 mm) crystals in many igneous rocks

Biotite, $K(Mg,Fe)_3AlSi_3O_{10}(OH,F)_2$, black flakes of mica

Calcite, $CaCO_3$, generally white or clear, but sometimes black or other colors, rhombohedral cleavage, softer than steel or glass, fizzes when dissolved in acid, as described in the following chemical reaction:

$CaCO_3 + 2H^+$ (acid) = Ca^{2+} (calcium in solution) + H_2O + CO_2 (carbon dioxide released into the air)

Celadonite, $K(Mg,Fe^{2+})(Fe^{3+},Al)Si_4O_{10}(OH)_2$, green clay mineral

Chalcedony, a fine-grained variety of quartz, SiO_2, pale yellow and milky white

Clinopyroxene, $Ca(Mg,Fe)Si_2O_6$, black or dark green, hard mineral common in basalt and andesite

Cristobalite, SiO_2, similar to quartz

Goethite, FeOOH, orange, rust-colored mineral, usually coating other rocks

Hematite, Fe_2O_3, red (giving some rocks a pink color); also occurs as small (generally less than 1 mm long) black crystals in igneous rocks, in a solid solution with ilmenite, $FeTiO_3$

Hornblende, $Ca_2(Mg,Fe)_4Al(Si_7Al)O_{22}(OH,F)_2$, black prisms, common in many igneous rocks

Kaolinite, $Al_2Si_2O_5(OH)_4$, white clay mineral

Magnetite, Fe_3O_4, black, magnetic, generally in a solid solution with ulvospinel, Fe_2TiO_4

Meta-autunite, $Ca(UO_2)_2(PO_4)_2 \bullet 2\text{-}6H_2O$, yellow, radioactive, fluorescent in UV light

Monazite, $CePO_4$, occurs as small (less than 1 mm) crystals in many igneous rocks, commonly contains many of the light rare earth elements in these rocks

Montmorillonite, $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$, part of the **smectite** group of clay minerals, also called **bentonite**, generally white or cream-colored but can be dark brown, red, or black, depending on impurities; because of its property of swelling when wet, it is used in drilling muds in oil fields

Opal, $SiO_2 \cdot nH_2O$, generally white

Orthopyroxene, $Ca(Mg,Fe)Si_2O_6$, black or dark green, hard mineral common in basalt and andesite

Phosphuranylite, $Ca(UO_2)_4(PO_4)_2(OH)_4 \bullet 7H_2O$, yellow, not fluorescent in UV light

Plagioclase, a feldspar solid solution dominantly between the end members albite, $NaAlSi_3O_8$, and anorthite, $CaAl_2Si_2O_8$, with lesser amounts of $KAlSi_3O_8$; with cleavage and striations from twinning within the crystals, clear when unaltered, commonly white when altered partially to clay minerals

Quartz, SiO_2 (silica), clear or white with conchoidal fractures (like glass, with no cleavage planes); scratches steel and glass

Sabugalite, $HAl(UO_2)_4(PO_4)_4 \cdot 16H_2O$, yellow, radioactive, fluorescent in UV light
Sanidine, a feldspar solid solution dominantly between the end members potassium feldspar, $KAlSi_3O_8$, and lesser albite, $NaAlSi_3O_8$, with small amounts of anorthite, $CaAl_2Si_2O_8$, clear to white; with cleavage
Titanite, $CaTiSiO_5$, occurs as small (less than 1 mm) crystals in many igneous rocks
Uraninite, UO_2, black
Uranophane, $Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$, yellow to amber brown, radioactive, fluorescent in UV light
Uranospinite, $Ca(UO_2)_2(AsO_4)_2 \cdot 10H_2O$, lemon yellow to yellow green, radioactive, fluoresces bright lemon yellow in short UV light and yellowish green in long UV light, rare mineral derived from the alteration of uraninite and primary arsenic minerals
Weeksite, $K_2(UO_2)_2(Si_2O_5)_3 \cdot 4H_2O$, yellow, radioactive, fluorescent in UV light, radiating crystals
Xenotime, YPO_4, occurs as small (less than 1 mm) crystals in many igneous rocks, commonly contains many of the heavy rare earth elements in these rocks
Zircon, $ZrSiO_4$, occurs as small (less than 1 mm) crystals in many igneous rocks

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Rock Types

Intrusive igneous rock types have chemically equivalent extrusive (volcanic) rock types. With increasing silica concentrations (from lowest in gabbro to highest in granite), the common igneous rocks are:

Intrusive		Extrusive
Gabbro	=	**Basalt**
Diorite	=	**Andesite**
Granodiorite	=	**Dacite**
Granite	=	**Rhyolite**

Pumice is a highly vesicular (lots of holes) and therefore low-density volcanic rock, composed predominantly of glass, but it may also contain crystals. It is pyroclastic (erupted from a volcanic explosion and deposited from the air, rather than flowing as lava). **Tuff** is composed mostly of small (millimeter sized and smaller) shards of volcanic glass, also derived from a volcanic explosion. The glass shards, crystals, and occasional rock fragments erupted into the air are termed "ash." Pumice and tuff generally are rhyolitic or dacitic in chemical composition.

Unconsolidated sediments in the area include fine-grained clay and silt (deposited in lakes), sand (deposited in streams and dunes), gravel (deposited on the shores of lakes and in stream channels), **alluvium** (a mixture of clay, silt, sand, and gravel, generally deposited by streams), and **colluvium** (a mixture of soil material and rock fragments deposited by rainwash, sheetwash, or slow downslope creep on the sides of hills). Sediments classified by size of particles include **clay** (less than 1/256 mm in diameter), **silt** (1/256 to 1/16 mm), **sand** (1/16 to 2 mm), granule (2 to 4 mm), pebble (4 to 64 mm), cobble (64 to 256 mm), and boulder (greater than 256 mm). **Gravel** consists predominantly of rounded rock fragments larger than 2 mm.

Sedimentary rocks are consolidated sediments. With increasing grain size, these include **claystone** (mudstone or shale), **siltstone**, **sandstone**, and **conglomerate**. **Tufa**, a type of limestone that forms in or along the shores of lakes, is composed primarily of the mineral calcite. It forms where groundwater from springs interacts with lake water or where alkaline lake water evaporates. **Caliche**, another variation of limestone, is calcite-cemented soil, alluvium, or colluvium, formed primarily when calcite precipitates from evaporating rainwater in an arid environment. **Chert** is a dense, silica-rich sedimentary rock generally formed in deep oceans but also in shallow lakes where abundant silica was available from volcanic ash. **Diatomite** is composed of microscopic silica fossils (algae) deposited in lakes.

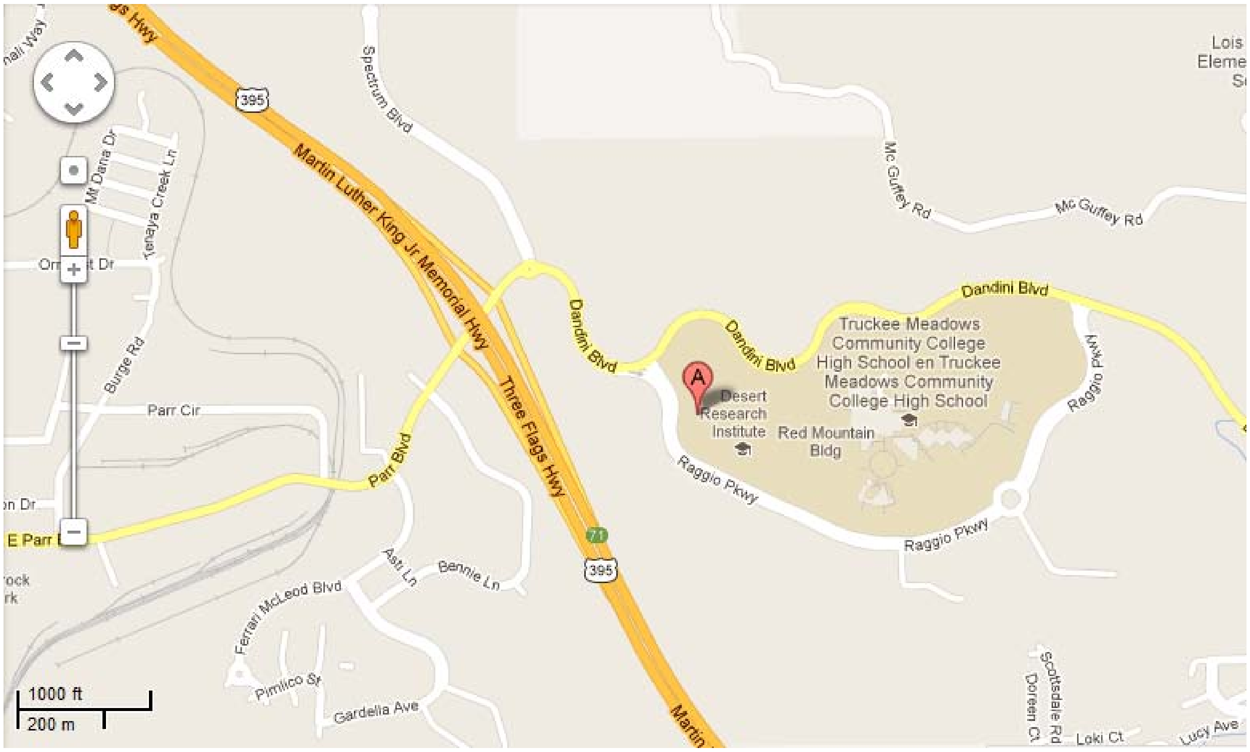

Figure 1. Location of the Great Basin Science Sample and Records Library, 2175 Raggio Parkway, Reno, NV 89512, on the west side of the campus of the Desert Research Institute. (Maps are taken mostly from Google Maps).

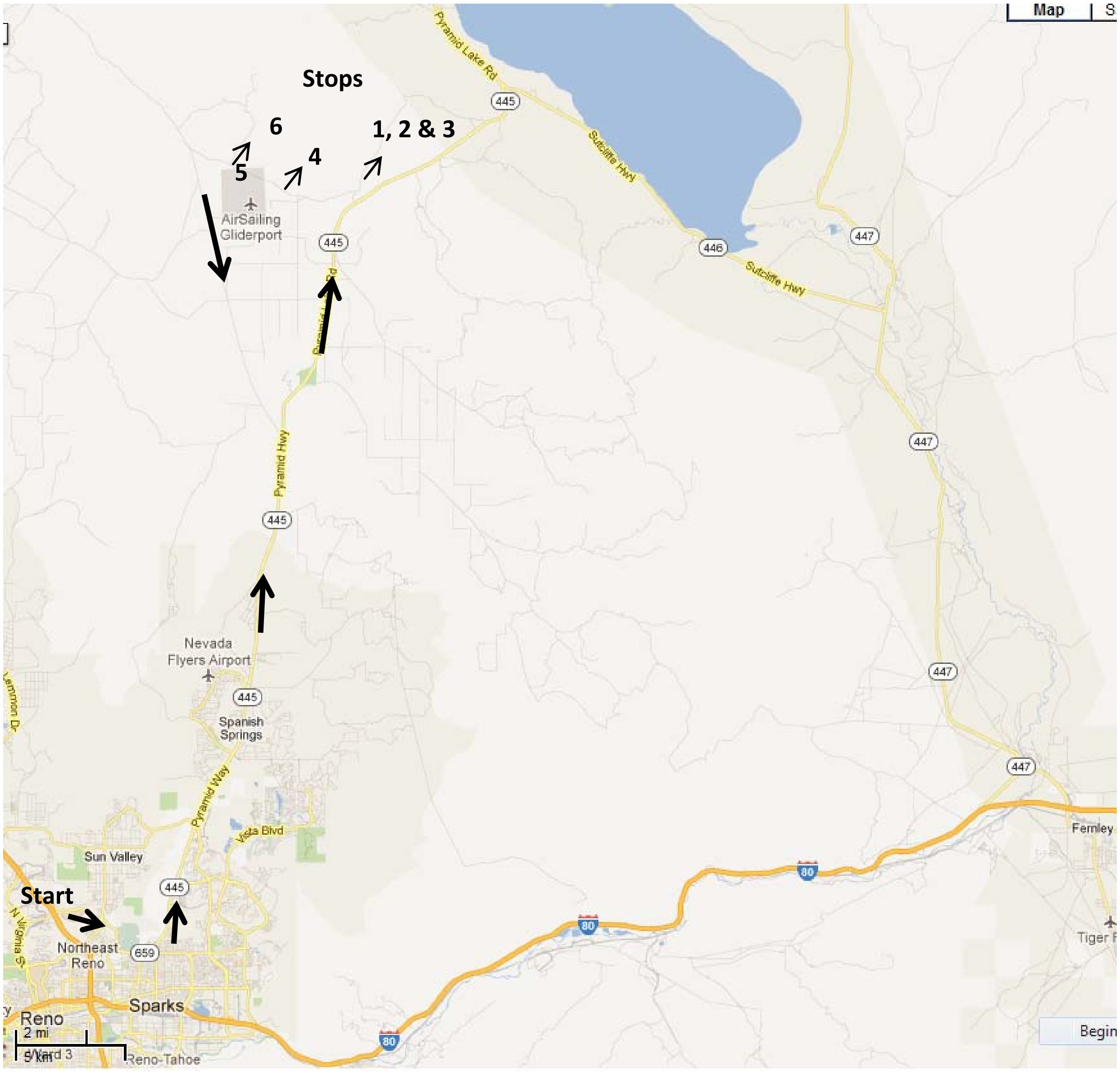

Figure 2. General location of field trip stops in the Virginia Mountains, west of Pyramid Lake.

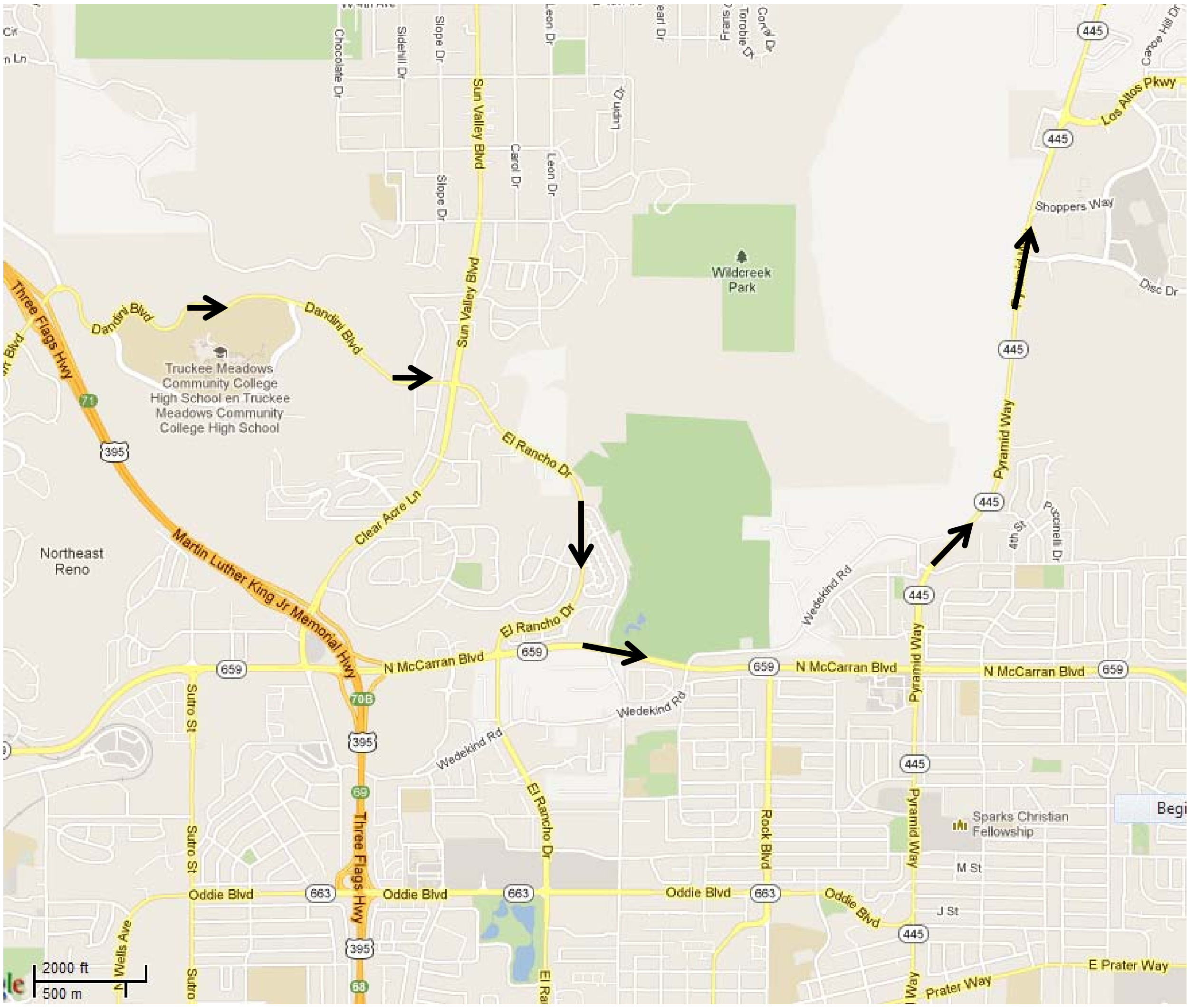

Figure 3. Route from the Great Basin Science Sample and Records Library (Start) to Pyramid Highway.

Figure 4. Route from the Pyramid Highway to Stop 1.

Figure 5. Locations of Stops 1, 2, and 3. Pass Stop 2 on the way to Stop 1. Return from Stop 1 via the same route to Stop 2.

Figure 6. Diatomite with impressions of leaves, Stop 1.

Figure 7. Sample of the tuff of Mullen Pass, with centimeter-size, flattened black pumice fragments and abundant lithic (rock) fragments, Stop 2.

Figure 8. Outcrop of the Tuff of Chimney Spring, Stop 3. Needle Peak, a spine within a rhyolite dome, is in the background at the right of the photograph.

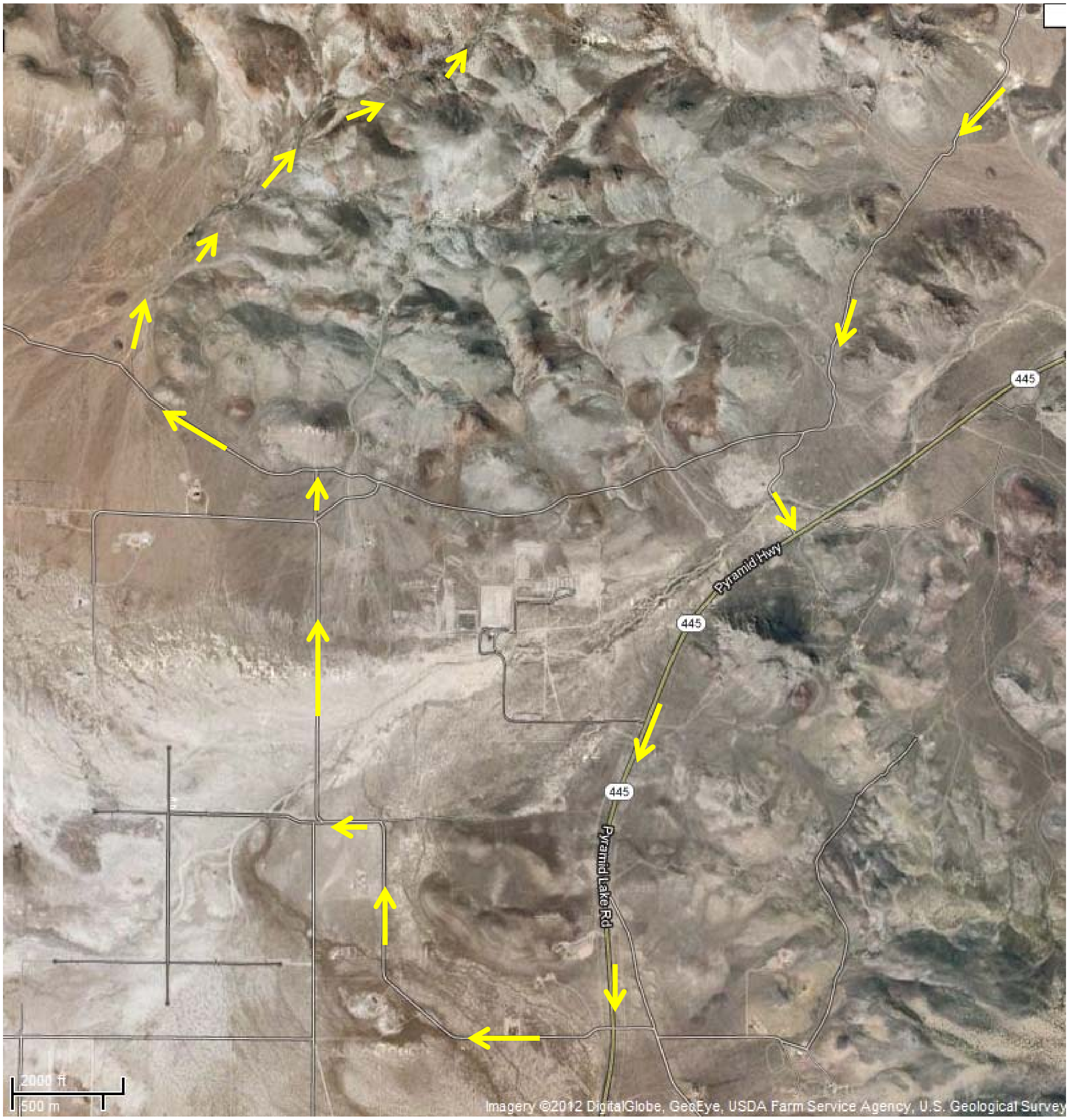

Figure 9. Route from Stop 1 to Stop 4.


Figure 10. View of the Incandescent Rocks Scenic Area from the gate. A U.S. Bureau of Land Management sign on the gate states that the area is designated by federal law as an area of critical environmental concern to protect its scenic value.

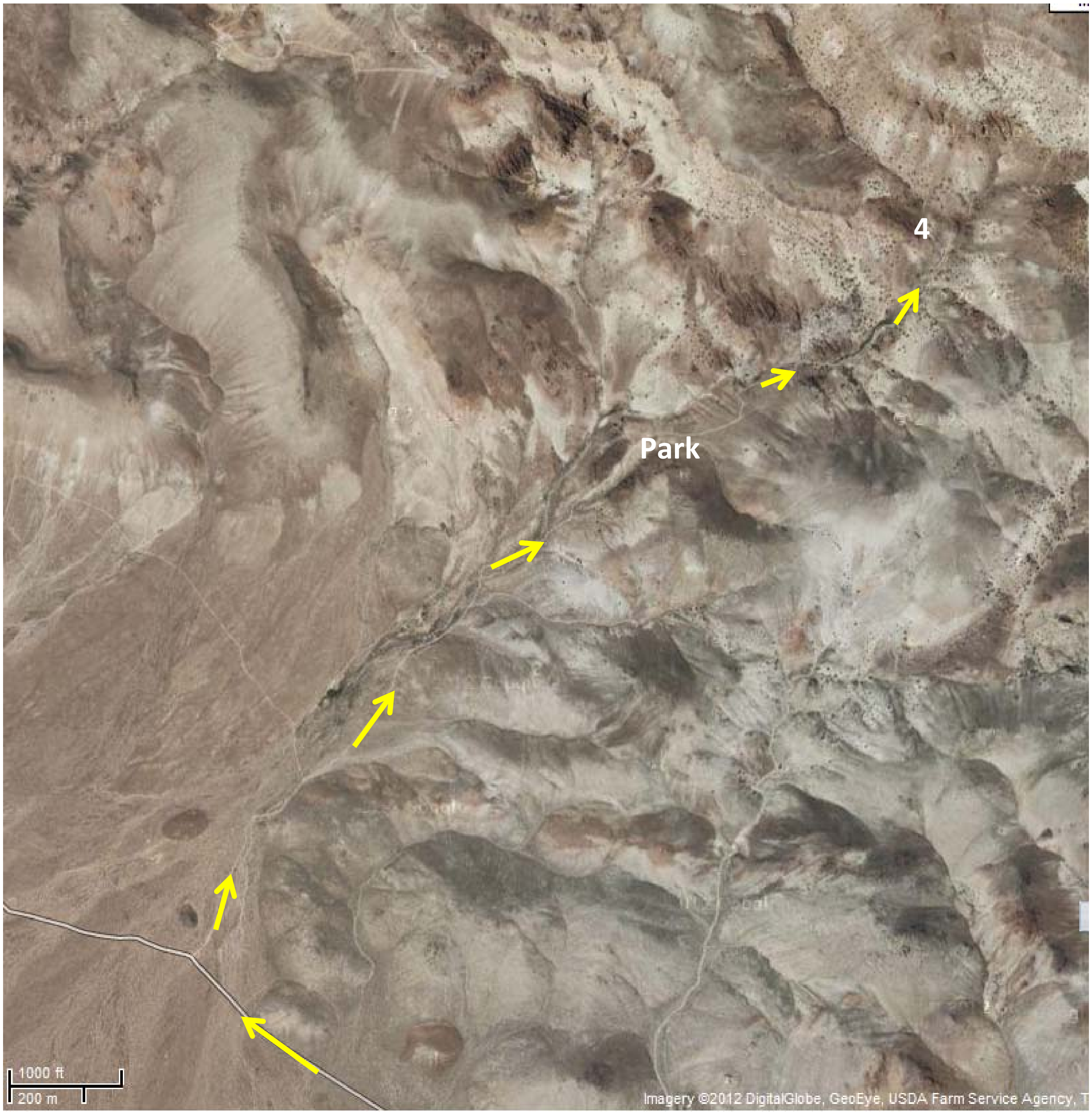

Figure 11. Route to Stop 4.

Figure 12. Hematite (pink) and goethite (orange) along fractures in the Nine Hill Tuff, Stop 4.

Figure 13. Dark, flattened pumice fragments in the Nine Hill Tuff, Stop 4.


Figure 14. Erosional spire in the Nine Hill Tuff, Stop 4.

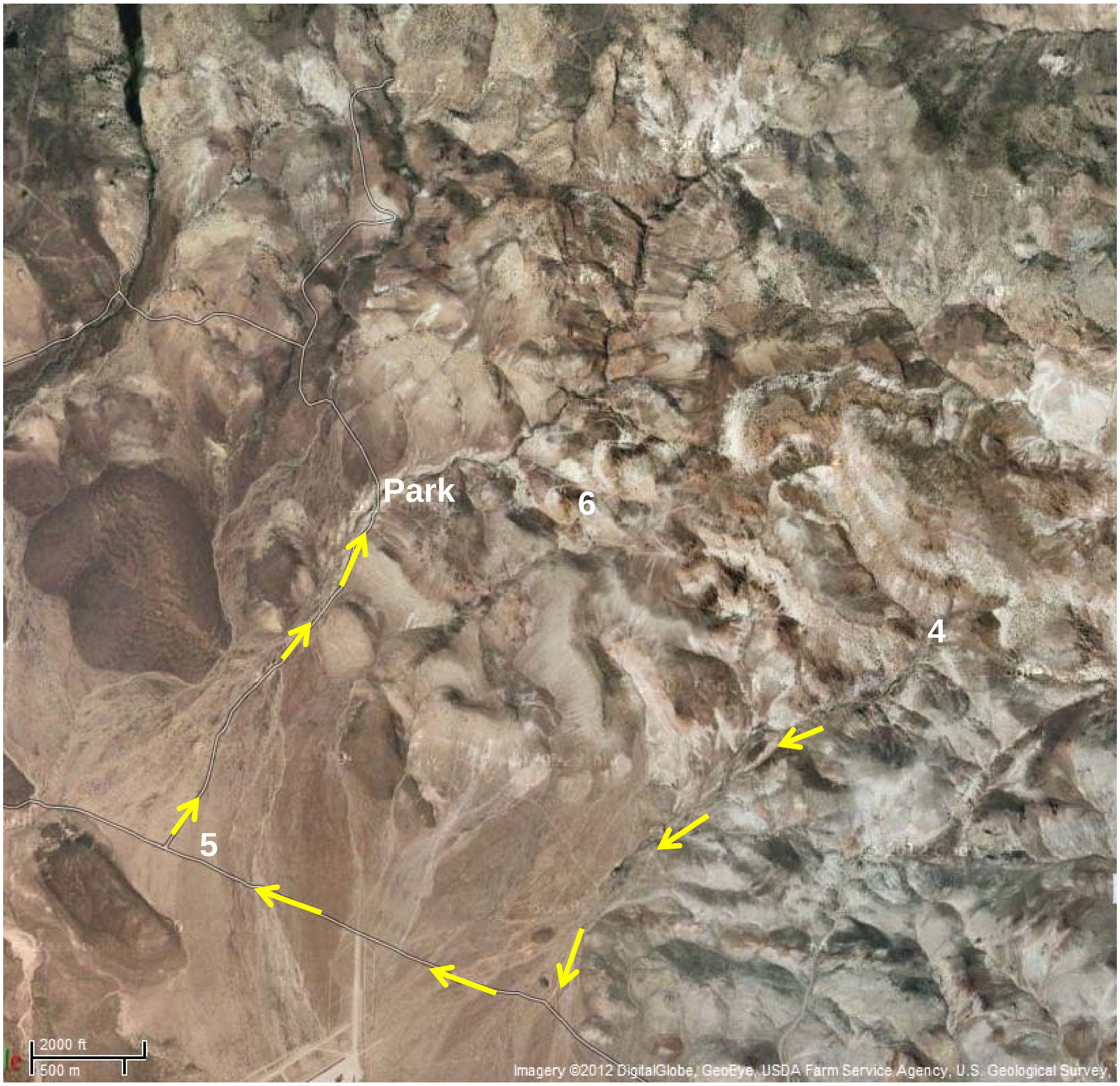

Figure 15. Route from Stop 4 to Stop 5.

Figure 16. Hiking route to Stops 6a and 6b.

Figure 17, Stop 6a. Entrance to the Delongchamps Mine. The sign, posted by the Nevada Division of Minerals, warns people that this is a dangerous mine. People should "STAY OUT. STAY ALIVE."

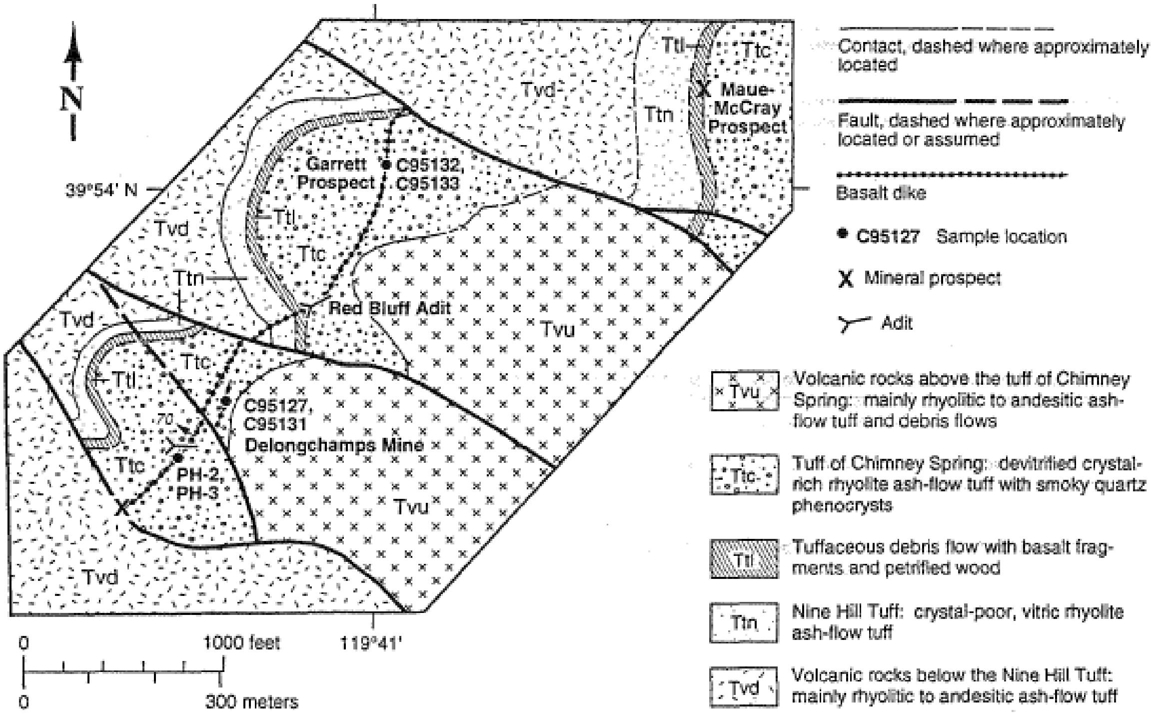

Figure 18. Geologic map of the Stop 5 area (from Castor and others, 1996). Stop 6a is at the Delongchamps Mine. Stop 6b is in the tuffaceous debris flow north of the Red Bluff Adit.

Figure 19. View of the dike cutting the Tuff of Chimney Spring and tuffaceous sedimentary rock at the Red Bluff Adit, looking northeast. Stop 6b is in the sedimentary rocks to the left (north) of the adit.

Figure 20. Close-up view of the andesite dike at the Red Bluff Adit, looking northeast. Stop 6b is to the left (north). Note the "STAY OUT. STAY ALIVE" signs.

Figure 21. Petrified wood embedded in tuffaceous debris flow, Stop 6b.

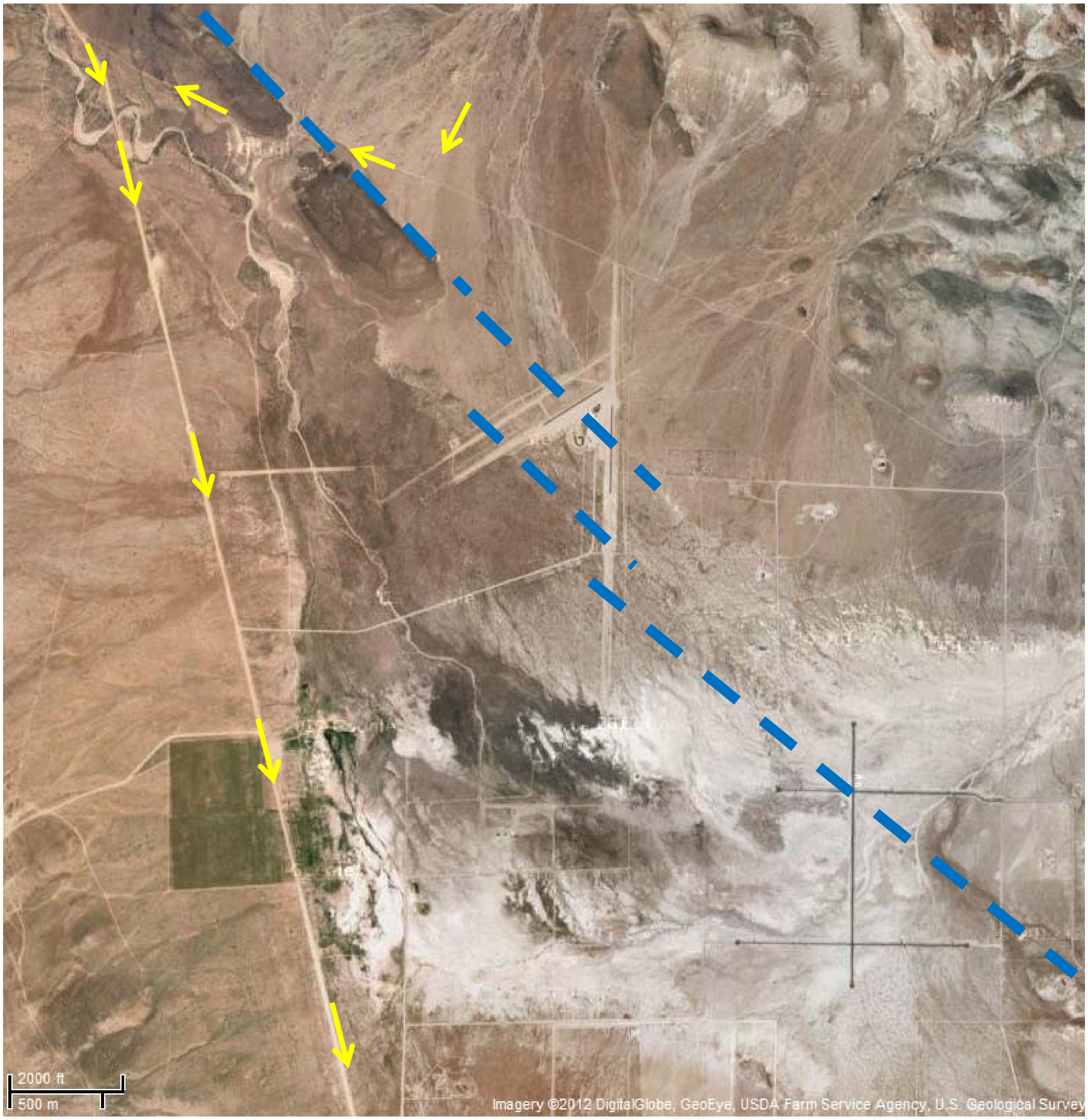

Figure 22. Route back to Sparks and Reno via the Winnemucca Ranch Road. The Warm Springs Valley fault zone is shown as blue dashed fault lines on this map.