DAY 2

The route for Day 2 depends on the availability of DOE escorts and activities within the Nevada Test Site. For this guide, Day 2 starts at Gate 100 at Mercury, Nevada, for badging. This trip mileage starts at the junction of the Mercury Bypass Road and the Jackass Flat Road (just west of Mercury), proceeds to the Yucca Mountain area for the first half of the trip, then goes to the National Nuclear Security Administration area on the Nevada Test Site for the second half of the trip.

CAUTION: Violation of security regulations on the Nevada Test Site and at Yucca Mountain are a serious matter. Prohibited items include cameras, binoculars, cell phones, GPS receivers, 2-way radios, and weapons. Geographic coordinates are provided for geographic reference.

0/0/0.0 Junction of Mercury Bypass Road and Jackass Flat Road. Go west on Jackass Flat Road.

10.3/10.3 The road to the right (3:00) leads north across Rock Valley and one of the locations where the Rock Valley Fault was trenched. The Rock Valley Fault is a left lateral strike-slip fault.

0.9/11.2 Ahead, we drop into Rock Valley and cross the Rock Valley fault. This fault is one of the more **active faults** in the area and has had a number of small magnitude earthquakes along it every year. The Little Skull Mountain earthquake in 1992 occurred in front (11:30) of Little Skull Mountain, along or near that fault. It had a magnitude of 5.8 (M = 5.8). It has been proposed that (Smith, et al., 2000) the Little Skull Mountain earthquake was triggered by the M = 7.5 Landers earthquake that occurred 20 hours earlier.

6.2/17.4 **Stone stripes** occur on either side of the road as we go through this pass. The rocks are basalt, with a type of **weathering surface** referred to as **desert varnish**. Desert varnish is commonly brownish black with a shiny surface luster and is formed through the steady accumulation of **eolian** dust over the years. In the 1990s, the desert varnish was studied to determine whether it could be used to measure how long the rocks were lying in the position they were found as a way to study the erosion rate. Those studies were inconclusive (Liu, 2003). Studies are now focusing on the chemical composition of individual layers whose composition may indicate wet and dry periods (Lui, 2003).

0.4/17.8 Jackass Flat is at 12:00. The Calico Hills are along the north side of the **flat** between 12:00 and 2:00.

3.3/21.1 Turn left onto Cane Spring Road.

1.3/22.4 Turn right toward the Yucca Mountain Project Sample Management Facility.

The Yucca Mountain Project Sample Management Facility is in the buildings 0.4 km [0.25 mi] south (9:00) on the west side of the road. Samples of rocks and other geologic materials from drill holes, trenches, geologic mapping, and tunnels are stored there. A complete record for each sample (i.e., its location, who handled it, and tests performed on it) is maintained here (DOE, 2006a).

1.5/23.9 At 11:00 to 12:00 are the Calico Hills. The type locality for the Topopah Spring Member of the Paintbrush Tuffs is on the far side of the hills. Shoshone Mountain is the high area on the skyline at about 1:00. Calico Hills is the type locality for the Calico Hills Formation (Table 1-1), which consists of rhyolite lavas, air fall, and ash flow tuffs. In the Calico Hills, this unit is **hydrothermally** altered, causing the bright colors. We will also see the effects of alteration on the colors of rocks at Stop 3A-1. These brightly colored rocks were often used by early prospectors as a guide in their mineral explorations in the 1800s and early 1900s in Nevada.

In addition to Yucca Mountain, the DOE investigated two other potential repository locations that bordered Jackass Flat: the Calico Hills area and an area just east of Jackass Flat in the Wahmonie Flat area that we will drive by later today. Based on geophysical data and the occurrences of hydrothermal alteration zones, both sites were initially interpreted to be underlain by shallow granitic intrusives. The Calico Hills are a northeast-trending elongated dome (**anticline, see fold**) structure, with Paleozoic rocks in the core surrounded by younger Miocene volcanic tuffs and lavas. The doming was interpreted to be the result of a shallow granitic intrusion. The surface of the Calico Hills that we see from here is underlain by the Calico Hills formation, which is older than the Paintbrush Tuffs at Yucca Mountain (Table 0-3) and suggests a fault in Fortymile Wash between Yucca Mountain and the Calico Hills. However, there is no other indication of a fault in this area. Near the center of the dome, exploratory well U 25A-3 was drilled to determine the depth to the inferred intrusion. Although the drill hole was drilled to a depth of 771.2 m [2,530 ft], it only encountered the Mississippian Eleana Formation. However, below a depth of 416.1 m [1,365 ft], the rocks were thermally altered, suggesting a nearby intrusion.

0.0/0.0 Turn left and reset the odometer to 0.00 so that beyond this point, any trips that enter through Gate 510 will begin at the same mileage from this point on.

0.6/0.6 The large building at 9:00 is the engine maintenance assembly and disassembly building (EMAD).

The Nuclear Rocket Development Station complex was constructed in the late 1950s and operated until 1971. It was used in the Rover program, a nuclear rocket development and test program, and for the Pluto program, which developed and tested a nuclear ramjet. Although never implemented, the development and testing of both projects were considered successful.

The engine maintenance assembly and disassembly facility was constructed in 1965 and was the largest {42.7 m [140 ft] long × 20.1 m [66 ft] wide × 23.2 m [76 ft] high} hot cell in the world. The building is 8 stories high and contained 9,290.3 m^2 [100,000 ft^2] of floor space. At the engine maintenance assembly and disassembly facility in 1980, 11 fuel assemblies from the Turkey Point Nuclear Power station were loaded into stainless steel canisters before being transferred to the Spent Fuel Test-Climax site at the north end of Yucca Flat (Stop 2-6). After the 3-year test was completed, the canisters were returned to the engine maintenance assembly and disassembly facility. In 1986, the **spent fuel** assemblies were repackaged and shipped to the Idaho National Laboratory for storage (see discussion, Stop 2-6).

On some trips, it may be necessary to sign in at Ranch Control in the **Exploratory Studies Facility** (**ESF**) area rather than going directly to Stop 2-1.

CAUTION: Arrangements must be made with Ranch Control to obtain a two-way radio.

0.2/0.8 Road crosses the Jackass and Western Railroad tracks (this was used to move equipment in the development of the nuclear rockets).

3.0/3.8 Geography seen from this location includes the following:

10:00	Amargosa Valley, with Funeral Mountains on the far side
11:00	Busted Butte, [look for the fault (Figure 2-1)]; offset welded tuff units
1:00	Fran Ridge [disturbed ground near the south end of ridge is Large Block Heater Test site (Stop 2-1); crest of Yucca Mountain is smooth horizon]
2:00	Alice Ridge with Yucca Mountain beyond
3:00	Fortymile Wash Canyon

2.0/5.8 Water storage bladder along left side of road.

0.1/5.9 Water well J–13 at 10:00.

0.3/6.2 Fortymile Wash. Here the wash has incised about 15 m [50 ft] below the alluvial surface as compared to 1 m [3.3 ft] near Stop 1-6. Also notice the characteristics (clast size, sorting, and layering) of the alluvium as we drive across the wash. This bedding may be representative of the alluvium in the area beneath the reasonably maximally exposed individual.

0.5/6.7 Turn left onto road that leads to the crest of Yucca Mountain.

1.3/8.0 Turn right and follow road to Stop 2-1.

0.4/8.4 Stop 2-1: Large Block Heater Test

The Repository Host Horizon (location of the **emplacement drifts**) consists of four zones (i.e., upper lithophysal, middle non-lithophysal, lower lithophysal, and lower non-lithophysal) in the Topopah Spring Tuff of the Paintbrush Group (Tables 0-3 and 1-1). At this site, one of the first tests to study the thermal effects of heating of the Topopah Spring Tuff was conducted. A 3 × 3 × 4.6-m [10 × 10 × 15-ft] block was carved from the middle non-lithophysal zone of the Topopah Spring Tuff. Temperature, moisture, distribution, and block deformation were monitored during the 13-month test (Lin, et al., 1998). As part of the large block characterization, more than 2,400 individual fractures were mapped and input into an EarthVision™ model (Wagoner, 1999). This provided information and data that were useful in designing subsequent thermal tests. Return to road to crest.

0.4/8.8 Right turn onto Yucca Crest Road.

0.3/9.1 Busted Butte at 12:00.

1.6/10.7 Boundary Ridge at 3:00.

1.5/12.2 Looking between 11:00 and 1:00 in this area, we get a perspective of the eastward dip of the tuffs beneath Yucca Mountain.

2.5/14.7 Approximate location of South Ramp of Exploratory Studies Facility, several hundred feet below the road. South portal is about 1.2 km [0.75 mi] east (3:00) of here.

1.5/16.2 Crest of Yucca Mountain. Turn left.

0.1/16.3 Stop 2-2: Crest of Yucca Mountain

Purpose

This stop provides an opportunity for an overview of the geology, hydrology, and culture of the Yucca Mountain area. The main focus of this stop is to observe and discuss the effects of climate, gravity, running water, and wind on the site and surrounding terrain, as well as the evidence of geologic processes that may produce potential hazards such as earthquakes, volcanism, **landslides**, and changes to the groundwater system. In addition, it provides an opportunity to discuss the local geography, political entities, **demographics**, land use, and natural resources.

Yucca Mountain Area Geography

To the north (12:00) is the northward extension of the crest of Yucca Mountain; the ridge beyond is the southern boundary of the Timber Mountain–Claim Canyon caldera complex (Figure 0-1). Moving clockwise at 1:00 is Fortymile Canyon. Between 1:00 and 2:00 are the Calico Hills, with Fortymile Wash in the foreground and Shoshone Mountain behind on the skyline. Alice Ridge, to the north and Fran Ridge to the south are the low ridges on this side of Fortymile Wash. Midway Valley is between Alice Ridge and the Exploratory Studies Facility. Across Fortymile Wash at 3:00 is Jackass Flat with Skull Mountain on the horizon. Between 3:30 and 4:30 is Little Skull Mountain with the Spring Mountains in the distance. The Striped Hills are at 5:00 and the northern Amargosa Desert at 5:30. On a clear day, Eagle Mountain, a triangular mountain in the distance, can be seen. It is just south of Death Valley Junction, California. Across the Amargosa Desert between 6:30 and 8:00 is the Funeral Range. Peaks just visible above the Funeral Range are in the Panamint Mountains on the far side of Death Valley. The southern end of the Grapevine Mountains, the northward continuation of the Funeral Mountains, is at 8:00 and passes out of view behind Bare Mountain on the west side of Crater Flat. The Sterling gold mine is near the base of Bare Mountain at about 9:00. The canyon just below this stop is Solitario Canyon, with Jet Ridge on the west side of the canyon. On a very clear day and when snow covered, the Sierra Nevada Mountains, 161 km [100 mi] away, can be seen from Yucca Crest at about 9:30. In Crater Flat, the cinder cones from north to south are Black, Red, and Little Cones, respectively. These volcanoes are about 1 million years old. The low dark ridges in south central Crater Flat, at about 7:00, are the remnants of a 4-million-year-old basalt complex. The 78,000-year-old Lathrop Wells cinder cone is visible at about 6:30.

Figure 2-1. View of Yucca Mountain area.

Geologic Setting

To adequately evaluate the safety of repository operations and the long-term performance of the potential repository, some knowledge of geologic and hydrologic processes within 100 km [62.1 mi] of Yucca Mountain is needed. This would include, but is not limited to, faults and associated seismicity, neotectonics, and hydrologic flow, which have been seen and are being discussed at other stops.

Yucca Mountain Geology

The geology at Yucca Mountain is relatively well documented (Figure 2-2). The base of the Miocene tuffs is 1,220 to 1,830 m [4,000 to 6,000 ft] or more below the surface. The tuffs overlie Paleozoic and older rocks such as those seen at Stops 1-3, 1-4, and 1-5. Figure 2-2b shows that the contact between these rocks is highly irregular, reflecting preexisting topography and subsequent faulting. Because of the faulting, as shown in Figure 2-2, the tuffs are tilted or rotated down and dip to the east at 5–10°. This is similar to the rotation along the Wild Horse Pass Fault shown in Figure 1-9. Large faults (the Solitario Canyon fault to the west and the Bow Ridge fault to the east) bound the repository block. Smaller faults, like the Ghost Dance fault, cut the repository block (Potter, et al., 2004, 2002). The tuff stratigraphy is simplified in Figure 2-2. More detailed Yucca Mountain stratigraphy is given in Table 1-1.

Yucca Mountain Hydrology

Introduction

In the early 1950s, groundwater flow from a potential high-level nuclear waste repository was recognized as the most likely route for radionuclide migration to the accessible environment. Because of this, water movement and geochemistry have been extensively studied at Yucca Mountain. A generalized flow path for a drop of water from the surface above the repository to the accessible environment includes vertical flow in the **unsaturated zone** to and through the repository to the water table 183 m [600 ft] below the potential repository. At the water table, the movement would become horizontal and travel in an east to southeast direction (Figure 2-3) toward the accessible environment (Stop 1-6).

Water Table

The water table is the surface between the top of the saturated zone and the bottom of the **vadose zone**. In most areas, the shape of the water table approximates the topography of the Earth's surface. In most uniform homogeneous rocks within the saturated zone, hydrologic flow is driven by gravity and is perpendicular to the contour lines of equal elevations that describe the shape of the water table. In Figure 2-3, the water flow would be to the east if the rocks were uniform and homogeneous. In nonhomogeneous rocks, the direction and magnitude of water flow is also influenced by the heterogeneties in the rocks, such as faults, fractures, and low permeable aquitards. Flow in these rocks is influenced by interaction of gravity-driven flow and the inhomogeneties in the rocks. At Yucca Mountain, most of the faults trend nearly north–south and give the ground water movement a southeastwardly direction. Near the compliance boundary, the flow is southerly (Figure 2-3).

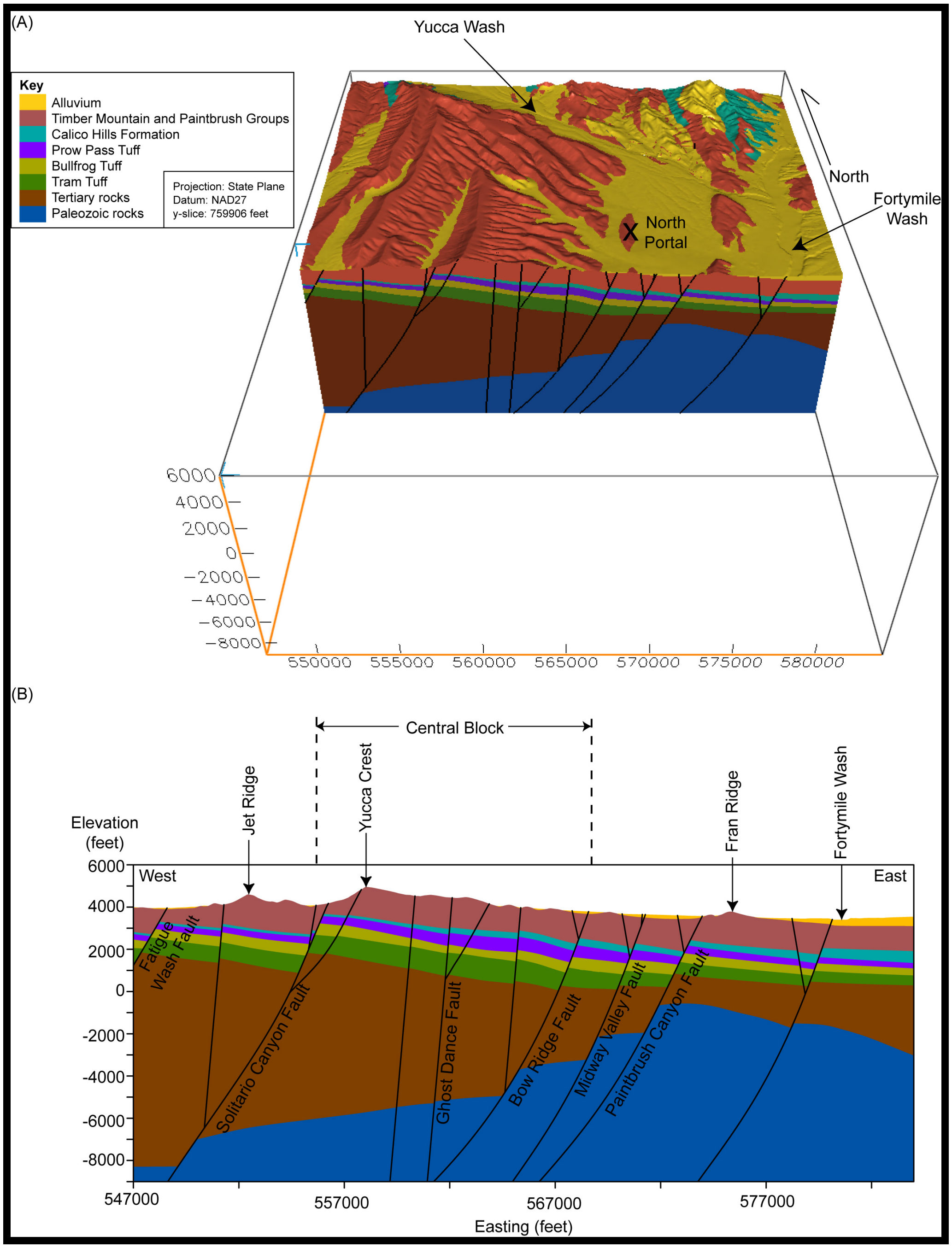

Figure 2-2. Interpreted geologic structures at Yucca Mountain. (A) Isometric model of North Portal (X) region. Note that many fault traces are covered by alluvium. (B) Cross section showing prominent faults and eastward-tilted beds. Note Calico Hills formation below Timber Mountain and Paintbrush groups.

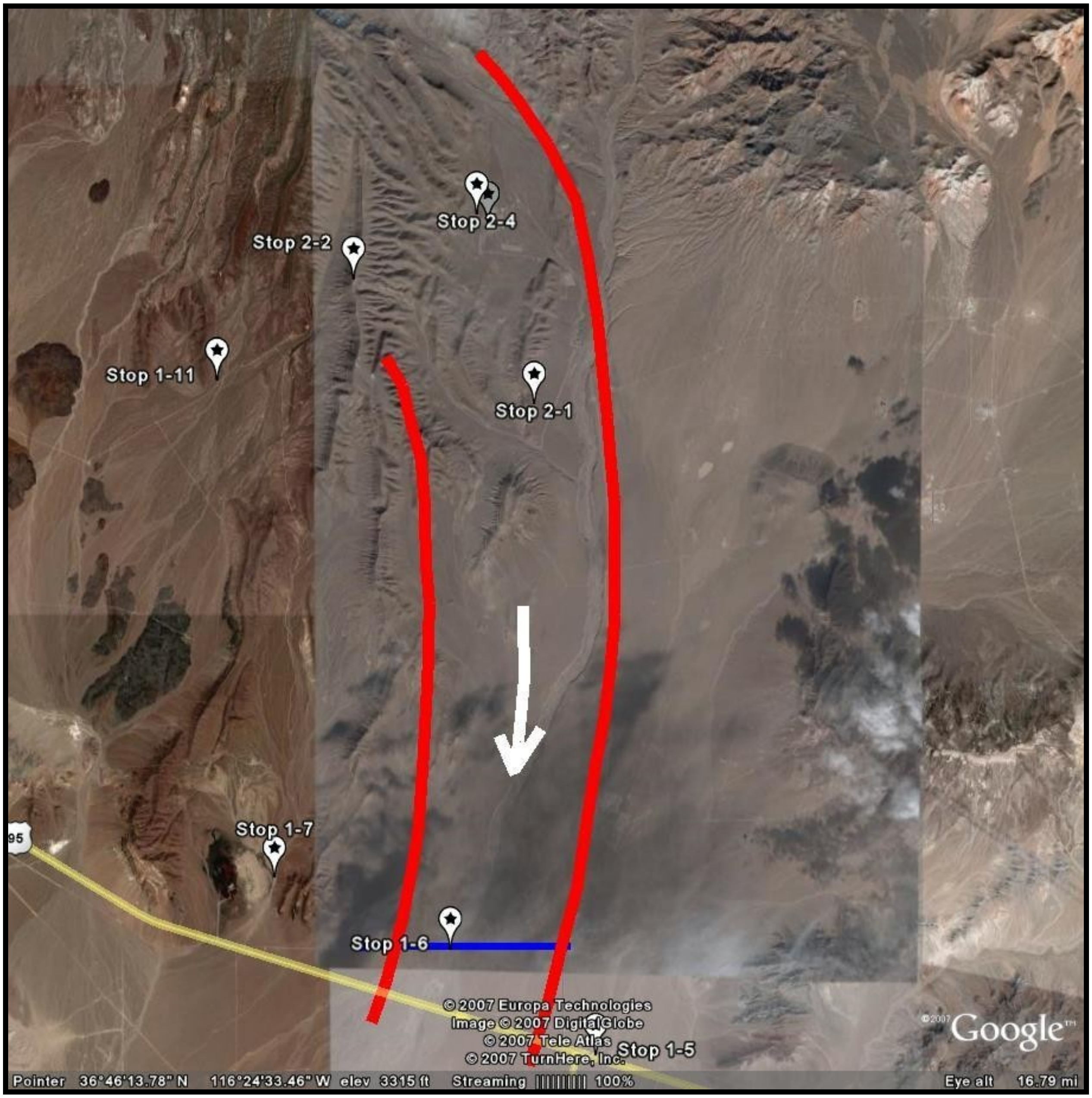

Figure 2-3. Approximate boundaries (red lines) of proposed east and southeast groundwater flow paths from Yucca Mountain toward the compliance boundary (blue line) and US Highway 95 (yellow line). Note Stop 2-3 is partially covered by Stop 2-4 marker.

Unsaturated Zone

Studies of the unsaturated zone hydrology have focused on infiltration from the surface and downward migration of water through the unsaturated zone. In addition to precipitation, four features of the site that control water infiltration and movement through the unsaturated zone are (i) vegetation, (ii) alluvium or colluvium thickness, (iii) faults and lithologic breaks, and (iv) lithologic characteristics.

The uptake and transpiration of infiltrating water by plant roots combined with bare soil evaporation reduce the downward migration of water below the root zone. However, the arrival of nonnative plants has reduced the effectiveness of this process by crowding out the native species, which have deeper root systems and germinate closer to the monsoon season in southern Nevada (Groeneveld, et al., 1999; see Appendix A).

In alluvium and colluvium, infiltrating water is slowed by imbibition into pores and by adsorption onto rock and mineral fragments. The downward migration of water into the underlying tuffs is greatly reduced when the alluvium thickness exceeds 1 to 2 m [3.3 to 6.6 ft]; thus infiltration is greater on ridges with thin colluvial cover than in washes with thicker accumulations of alluvium.

In the unsaturated zone, water moves both vertically downward under the influence of gravity and horizontally as influenced by features such as inclined bedding and dipping faults. The control of the downward movement by faults was observed following a period of heavy precipitation {32.4 cm [12.75 in]} between October 2004 and February 2005 in the South Ramp area of the Exploratory Studies Facility (Finsterle and Seol, 2005). In addition, the **Alcove** 8/**Niche** 3 fault test concluded that flow behavior was clearly controlled by the fault. Horizontal movement is controlled largely by stratigraphic layering, dip, and lithology (Zhou, et al., 2006).

In the unsaturated rocks at Yucca Mountain, there are two hydrologic zones that slow the downward movement of water. Above the repository, the unit referred to as the PTn (Table 1-1, Stop 2-11) consists of several nonwelded and bedded tuffs. This sequence of tuffs retards the downward flow above the potential repository. Below the repository is the altered Calico Hills formation, which also acts as a barrier to downward flow. The alteration in the Calico Hills formation reduces the permeability and results in zeolites and clay minerals that can adsorb selected radionuclides, especially strontium and cesium.

Saturated Zone

When the downward movement of water reaches the saturated zone at the water table, it becomes mostly horizontal. Movement in the tuffs is predominantly through fractures until the tuff/alluvium interface is reached south of Busted Butte. When the flow enters the alluvium, the water moves through the pores between the clasts. Alluvium variations in grain size and caliche cementation cause the alluvium to be inhomogeneous. The flow in alluvium is no longer confined in the fractures, and it can disperse over a wider area in the downgradient direction. In addition, the alluvium contains clay minerals and calcite that can hold or retard selected nuclides.

Water Geochemistry

Geochemical investigations of water at Yucca Mountain have focused on (i) pore water in the unsaturated zone, (ii) perched water in the unsaturated zone, and (iii) water in the saturated zone. These studies have revealed a complex chemical evolution for these waters. The source of pore and perched waters is local precipitation (i.e., recharge in the vicinity of Yucca Mountain). Subsequently, the water chemistry evolves as this water interacts chemically (i.e., ion exchange and dissolution of the rocks it passes through). In the saturated zone below Yucca Mountain, most of the water has moved downgradient from recharge areas to the north and northeast, especially from the higher Timber Mountain and Pahute Mesa areas. The groundwater in volcanic aquifers is characterized as sodium bicarbonate with lower total dissolved solids and higher dissolved silica, compared with the water in the regional carbonate aquifer, which is characterized as calcium bicarbonate with higher total dissolved solids and lower dissolved silica.

USW UZ-6

The drill pad on the east side of this stop is the site of USW UZ-6, one of seven holes drilled in the study of the unsaturated zone. The hole was drilled with a vacuum reverse-air-circulation method of dry drilling. The 575-m [1,887-ft]-deep drill hole penetrated an estimated 77 percent of the saturated zone at this location {i.e., the water table is at an estimated depth of 747 m [2,450 ft]}. The hole bottomed in the Prow Pass Member of the Crater Flat tuffs (Table 2-1).

Table 2-1. Stratigraphic units in the hole USW UZ-6

Unit	Member	Depth
Paintbrush Tuff	Tiva Canyon	0–132 m [0–433 ft]
	Nonwelded Tuffs	132–138 m [433–453 ft]
	Topopah Spring	138–438 m [453–1,437 ft]
Calico Hills Tuff		438–483 m [1,437–1,585 ft]
Crater Flat Tuff	Prow Pass	483–575.2 m [1,585–1,887 ft]

Demographics, Climate, Biota, and Archeology

Most of this section is based on the Final Environmental Impact Statement by DOE (2002).

Political Boundaries: The California/Nevada state line lies a few miles this side of the Grapevine–Funeral Mountains and is nearly parallel to their trend. The potential repository is located in Nye County. For a short time in 1987, the legislature created Bullfrog County, a 373-m^2 [144-mi^2] enclave within southern Nye County. The purpose of Bullfrog County was to enhance the state's ability to receive funds from the federal government pursuant to the Grants Equal to Taxes provisions of the Nuclear Waste Policy Act. Following a challenge by Nye County in the Nevada District Court, the legislation was judged to be unconstitutional and subsequently was repealed by the legislature in 1989 (Nevada State Library and Archives, 2006). The Nevada Test Site boundary is to the east. The land we are on at this stop is a right of way granted DOE by the Bureau of Land Management to characterize the repository area. To the north is a similar right of way granted by the U.S. Air Force. In addition, the Western Shoshone also claim ownership of this land.

Demography and Land Use: The average population in number of people/mi^2 (permanent residents) in the viewing area is about 1.4 persons/mi^2 in Nye County and 140 persons/mi^2 in Clark County. Several busloads of Nevada Test Site and Yucca Mountain Project workers commute from Las Vegas daily. Observable land uses include Nevada Test Site multiple tests, military air base, Bureau of Land Management open range, irrigation/agriculture, mining, rural development, roads.

Site Climatology: DOE established permanent meteorological stations at nine sites around Yucca Mountain to monitor (i) precipitation, (ii) temperature, (iii) barometric pressure, (iv) relative humidity, (v) wind speed, (vi) wind gusts, and (vii) solar radiation (Sharp, 2007). Site 2 is about 2.1 km [1.3 mi] north of this stop. The local climatology of a rugged site such as Yucca Mountain can be variable as it is influenced by local topography, drainage channels, rock outcrops and cliffs, and hill slope direction and angle, as well as regional and global factors, such as the El Nino–Southern Oscillation events (Sharp, 2007). The average annual temperature varies from 15.1 °C [59.2 °F] at Site 6 (WT-6) to 18.2 °C [64.8 °F] at Site 9 (Gate 510). The mean annual precipitation ranges between 213.9 mm [9.1 in] at Site 6 and 113.3 mm [4.5 in] at Site 9. The mean annual wind speed at a height of 10 m [32.8 ft] ranges from 2.6 m/s [5.8 mph] at Site 3 (Coyote Wash) to 4.5 m/s [10.0 mph] at Site 4 (Alice Hill), with a maximum 3-second gust speed at 10 m of 38.7 m/s [86.6 mph] up the road at Site 2. The strongest winds are associated with thunderstorms (Sharp, 2007). The near-surface {0 to 30 m [0 to 98.4 ft]} wind direction is variable throughout the year. At higher altitudes {3,000 to 16,000 m [9,843 to 52,493 ft]}, the winds blow toward the east (NNE to SSE) 80 percent of the time (Miller, et al., 1982, Figure 4). Some annual meteorological values measured on the Crest of Yucca at Site 2 are given in Table 2-2. Strong winds such as hurricanes are rare; however, heavy rainfall is often associated with the monsoons that commonly occur in the southwestern United States in July and August. Within the state of Nevada there were 49 tornados between 1950 and 1995. Over that time period, Nevada ranked 45th in frequency of tornados with a cost per person per year for tornados of $0.08 (The Disaster Center, 2009).

Biota: The Carter Flat/Yucca Mountain/Jackass Flat area is in the range of elevation and precipitation that supports the vegetative zone called “creosote-bursage” (56 percent of vegetation), with higher elevations dominated by blackbush. Observable wildlife includes 63 species of mammals of which 17 are rodents (e.g., long-tailed pocket mice are most abundant); 7 species of bats; 3 species of rabbits; 9 species of large mammals (e.g., mule deer, coyote, burros); 12 species of lizards; 14 species of snakes (most abundant are coachwhips and long-nosed); 27 species of reptiles [e.g., desert tortoise (endangered)]; pup fish (endangered); and 120 species of birds sighted (e.g., most common nesters are black-throated sparrows, morning doves, and exotics [e.g., great blue heron (hunting pupfish at Desert Spring Wildlife Refuge)].

Archeology: The area contains artifacts of American Indian culture such as fireplaces, cookware, and tools, among others. These sites and objects are protected and off-limits to visitors. The area was a hunting ground, and certain mountains are held sacred by the Western Shoshone people. Artifacts that may be observed on this trip, including arrowheads, should be left in place, photographed (when permitted camera is on hand), and reported to the trip leader for documentation.

Relevance to Reviewing a Potential License Application: The Yucca Mountain site covers land, mineral, and water rights under the jurisdiction of the State of Nevada, federal agencies, and the Western Shoshone government (disputed through a United Nations grievance process), and requires a Land Withdrawal Act of Congress to be reconstituted for control by the DOE–Yucca Mountain Project. In the 1980s, a prospector’s claims on Yucca Crest were bought out by DOE. Clarification of ownership is an integral part of Environmental Impact Statement process. Demographic and land use analyses are required to establish the reasonably maximally exposed individual and determine appropriate pathways for dose analyses. Also relevant to an Environmental Impact Statement, among other things, is information regarding appropriate levels of protection for protected and endangered species and honoring and protecting historical American Indian artifacts and burial grounds.

Table 2-2. Annual values for selected parameters at U.S. Department of Energy Meteorological Site 2. (Modified from Sharp, 2007)		
Parameter	**Units – Metric**	**Units – English Customary**
Temperature Length Pressure Speed Energy flux	°C – °Celsius mm – millimeter mb – millibar m/s – meters per second $MJ/m^2/d$ – megajoules per square meter per day	°F – °Fahrenheit in – inch in Hg – inch of mercury mph – mile per hour
Temperature		
Average	15.7 °C	60.3 °F
Highest daily	39.9 °C (7/9/02)	103.8 °F
Mean daily maximum.	32.7 °C (July)	90.1 °F
Lowest daily	−12.5 °C (2/6/89)	9.5 °F
Mean daily minimum	3.1 °C (December)	37.6 °F
Precipitation		
Annual average	183.1 mm	7.2 in
Maximum daily	50.0 mm (2/23/98)	2.0 in
Maximum 1 hr total	30.0 mm (July)	1.2 in
Annual Average Barometric Pressure		
Highest daily average	866 mb (2/10/02)	25.57 in Hg*
Lowest daily average	831 mb (2/27/97)	24.54 in Hg*
Annual Average Relative Humidity	28%	
Hour @ 0400 (Pacific Standard Time)	33%	
Hour @ 1600 (Pacific Standard Time)	22%	
Wind		
Mean annual speed @ 10 m	4.3 m/s	9.6 mph
Maximum 3-second gust @ 10 m	38.7 m/s (9/26/05)	86.6 mph
Prevailing direction	157° (SSW)	
Annual Average Daily Solar Radiation	19.9 $MJ/m^2/d$Megajoules/meter^2/ day	
Elevation	1,478 m	4,849 ft
* – Values not elevation adjusted to mean sea level		

The main objectives of the deep unsaturated-zone drilling and testing program were (i) to determine the **flux** of water moving through the unsaturated nonwelded and bedded tuff units and to determine whether perched water zones exist; (ii) to determine a vertical profile of water content, **water potential**, (see water) and other important hydrologic characteristics of the rock units penetrated; and (iii) to monitor, by downhole instruments, the hydrologic changes that occur over an extended span of time and to provide data to calculate flux in nonwelded and bedded tuff (Whitfield, et al., 1993).

Return to Fortymile Wash.

2.9/19.2 Ahead is Busted Butte. **Sand ramps** are noticeable along the west flank of Busted Butte. Erosion of the sand ramps revealed the Paintbrush Canyon Fault. Soil horizons that developed as the ramps were built up are offset by the fault. Age dating of the soil horizons and determining the number and amount of slip were used in determining the seismic history of the fault.

3.9/23.1 Turn left and proceed to Exploratory Studies Facility area.

1.7/24.9 Turn right into the Exploratory Studies Facility area.

0.4/25.3 Muck piles ahead on the left are from tunneling into Yucca Mountain during the excavation of the Exploratory Studies Facility Tunnel and the **Enhanced Characterization of the Repository Block** (see Exploratory Studies Facility) cross **drift**.

0.4/25.7 Ranch Control is on the right. Check in here.

0.2/25.9 Stop 2-3: Exploratory Studies Facility Tour

At this stop, staff from the Yucca Mountain Project will lead an underground tour and give several briefings. As we enter the tunnel, notice the size of the opening. The first 61 m [200 ft] were excavated using **drill and blast** technique. This provided a starting chamber for the **tunnel-boring machine**. At approximately 61 m [200 ft] into the tunnel, notice the change to a circular opening leading to a 7.6-m [25-ft]-diameter tunnel. This is where construction of the tunnel using the tunnel-boring machine began. In addition to discussions in the alcoves by DOE, we will proceed an additional 30.5 m [100 ft] into the tunnel where it intersects the Bow Ridge Fault. The fault is a west-dipping (75°) normal fault. Here Tiva Canyon tuff is in the footwall and pre-Rainier tuff in the hanging wall of the fault. The **fault zone** is about 2.7 m [8.9 ft] (Beason, et al., 1996) with a core zone about 0.35 m [1 ft] wide. Note the width and texture of the fault zone here. The next stop (Stop 2-4) will be at Trench 14, which was excavated through the fault at the surface and reveals significantly different features of the fault zone.

LUNCH

Leave stop and return to Exploratory Studies Facility entrance.

1.0/26.9 Turn right.

0.4/27.3 Turn right onto dirt road.

0.4/27.7 Turn right into parking area.

0.1/27.8 Stop 2-4: Trench 14

Excavation of Trench 14 initiated a discussion that lasted two decades. The discussion revolved around the origin of the solutions that deposited the calcite **veins** seen in the trench walls. One camp argued the solutions were hot and came from deep underground.[3] The second group argued the calcite was deposited from upslope runoff into which eolian carbonate dissolved then reprecipitated (Whelan, 2004). The National Academy of Sciences panel on Coupled Hydrologic/Tectonic/Hydrothermal Systems at Yucca Mountain (National Research Council, 1992) concluded there was no evidence to support Szymanski's hypothesis. The Bow Ridge fault zone is 3–5 m [10–15 ft] wide and contains blocks of Tiva Canyon tuff surrounded by calcite veins. Rainier Mesa tuff is on the downthrown side of the fault. Its history of motion along the fault and the developmental sequence of the veins is not easily decipherable. As you will recall at the last stop where the ESF tunnel crossed the Bow Ridge fault, the core zone is about 0.35 m [1 ft] wide.

Walk to the crest of Exile Hill. Here we can look out across the potential site of the waste handling surface facilities in Midway Valley. Figure 2-4 shows the facility layout. The two low ridges across Midway Valley are Alice Hill and Fran Ridge. They are identified on the right edge of Figure 2-4. As shown in Figure 2-4, the facility would extend about two-thirds of the way across Midway Valley. From this point above the North Portal, the facility would extend from the southwest to the northeast. The southeast area would be the location of the future rail yard and associated maintenance facilities. The rail line would enter the site from the south, along the west side of Fran Ridge. The waste would be transported to the waste handling facility area where it would be offloaded, processed, and loaded on a transport and emplacement vehicle for the trip to its designated storage location in the emplacement tunnels.

Extending northeast from the North Portal would be the potential nuclear waste handling facility consisting of a number of buildings—each with a specific waste handling and processing capability. In addition, there would be a number of nonnuclear support facilities, including warehouses, maintenance shops, and security buildings throughout the area. The waste handling facility would consist of the following structures (DOE, 2007):

Receipt Facility: At the receipt facility, waste canisters would be removed from the transportation casks and prepared for transfer to the appropriate waste handling facility. This facility also would prepare unloaded transportation casks and railcars for return to the National Transportation System for continued use.

Initial Handling Facility: As the first building scheduled for completion, the Initial Handling Facility would prepare high-level radioactive waste from government facilities and spent nuclear fuel from the U.S. Navy for disposal.

Canister Receipt and Closure Facilities: The Canister Receipt and Closure Facility would receive all disposable canisters, except for naval spent nuclear fuel canisters, and prepare them for disposal. The facilities would be built in phases.

Wet Handling Facility: The Wet Handling Facility includes a pool of water in which spent fuel rods would be removed from transportation casks, placed into transportation, aging, and disposal canisters, and prepared for disposal or aging.

Aging Pads: The aging pads would be near the waste handling facility and would temporarily store the waste until it reaches an acceptable temperature for underground emplacement.

[3] Szymanski, J.S. "Conceptual Considerations of the Yucca Mountain Ground Water System With Special Emphasis on the Adequacy of This System to Accommodate a High-Level Nuclear Waste Repository." Unpublished DOE report. 1989.

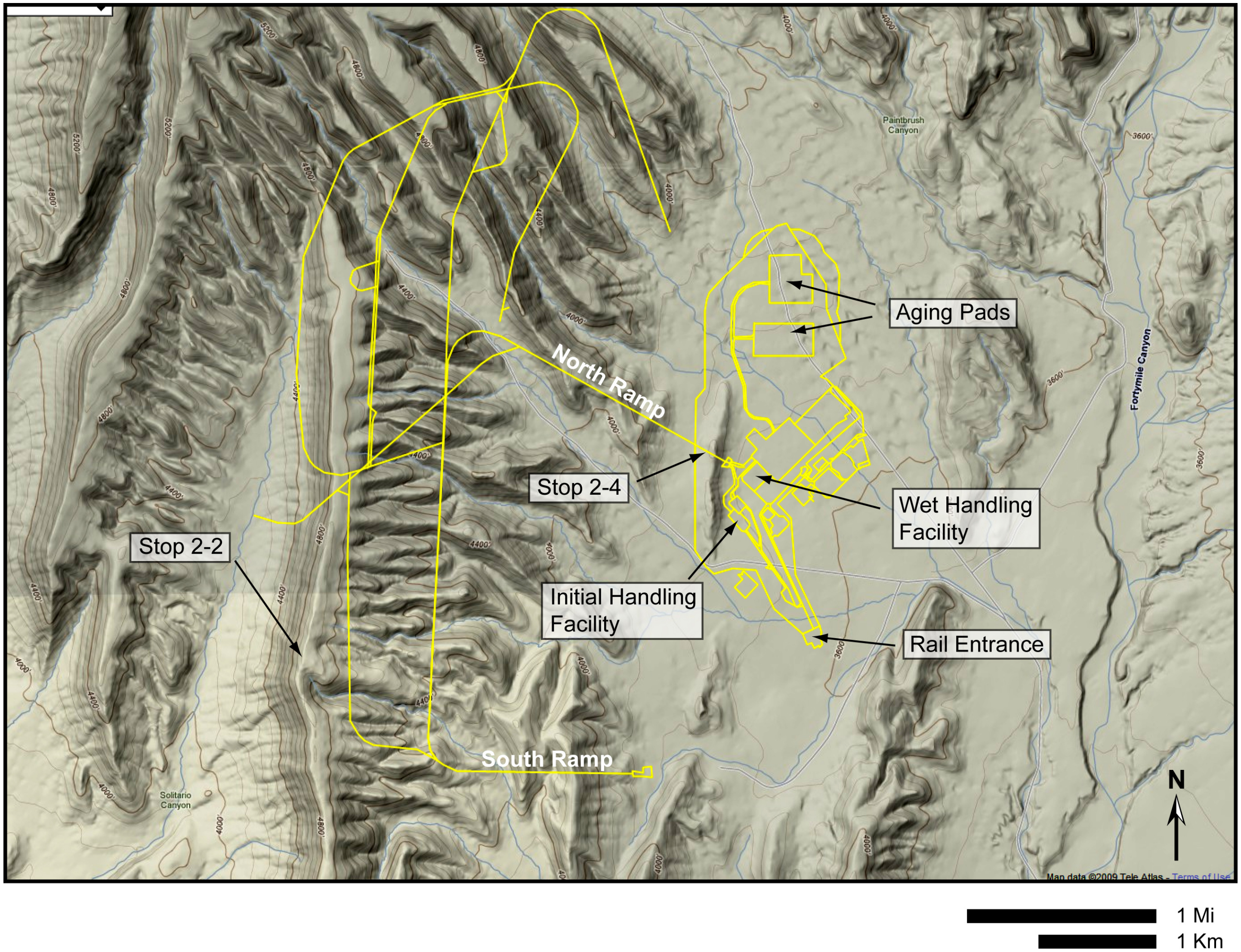

Figure 2-4. Map of potential repository area site plan. Geologic Repository Operations Area (GROA), surface and subsurface, digitized from DOE License Application General Information Figure 5-6, page 5-125 (DOE, 2008). Underlying terrain from Google Maps (8/17/09).

Return to intersection of Cane Springs and Jackass Flat Roads (previous 3.3/20.8 mileage) and **reset** odometer to 0.0/0.0.

0.0/0.0 Intersection of Cane Springs and Jackass Flat Roads. Proceed east on Cane Springs Road.

0.1/0.1 At 2:00 is the BREN Tower. This tower was used to study the effects of radiation by raising a reactor out of a pit beneath the surface. Dose was controlled by the height of the reactor above ground level. The tower is 465 m [1,526 ft] high.

1.0/1.1 At 10:00 is Midway Valley.

2.9/4.0 At 11:00 is the area known as Wahmonie Flat. This is another area DOE investigated as a potential site for the repository. Geophysical surveys indicated the area was highly faulted and it was rejected. This was also the site of a 1928 silver mining venture, where more money was made selling stock than mining ore.

7.1/11.1 Cane Spring is at 2:00. This spring forms along an impermeable section of the northeast-southwest-striking Cane Spring fault. The fault forced southward- flowing groundwater to the surface. This was a stagecoach stop on the Las Vegas to Beatty route in the early 1900s. A building still remains from those days.

6.2/17.3 Junction with Mercury Highway. Turn left.

5.4/22.7 Ridge to right underlain by Rainier Mesa tuff (Table 1-1).

1.0/23.7 CP Pass.

The nuclear tests were conducted and controlled from the buildings at 9:00.

1.8/25.5 News Knob at 9:00.

This was the location of the press during the early atmospheric tests in Yucca Flat. The benches remain on the east side (3:00) of road.

0.3/25.8 At 9:00 is Yucca Lake when flooded; however, most of the time it is the dry Yucca Playa.

This large white area is a playa—a dried up desert lake. After intense rainstorms, the playa (Yucca Lake) is filled with a few feet of water that disappears after several days to weeks. Several large north-northeast-trending fractures opened up in the south end of the lake in the 1960s, and water was observed draining from the lake down into the fractures. The north-northeast trend of the fractures is perpendicular to the minimum *in-situ* stress in southern Nevada, suggesting the fractures were of tectonic origin. Enough sediment has been washed into the cracks that they are healing. Similar fractures, or scars where they have rehealed, have been observed on other playas (Carr, 1974).

Continue north on Mercury Highway to BJ Wye.

7.8/33.6 BJ Wye.

Keep on Rainier Mesa Road to the left.

There are two theories about the origin of “BJ.” The first states that it represents Balloon Junction. Near here, balloons were filled with helium and then towed across the desert to the site of a nuclear test. The nuclear explosive was suspended from below the balloon. The balloon was tethered to the ground and the necessary arming and firing cables attached, then the balloon was raised to the planned height and the explosive detonated. This was one method of trying to reduce downwind radioactivity by reducing soil activation and atmospheric suspension of radionuclides. The second theory states BJ stands for Buster Jangle, the operational name for an early series of tests.

1.0/34.6 The Eleana Range is along the west side of Yucca Flat at 9:00 to 11:00.

The Eleana Range is composed of folded clastic rocks of the Eleana Formation. Hydrologically, this area is referred to as the Upper Clastic Aquitard and divides the regional carbonate into an upper and lower unit (see Introduction—Regional Hydrology).

Behind the Eleana Range on the skyline at 11:00 is Rainier Mesa. Rainier Mesa was the site of nuclear tests conducted in tunnels.

3.7/38.3 Take 2-03 Road to right.

3.0/41.3 Take Groom Lake Road to left.

1.0/42.3 Yucca Fault Scarp at 9:00. To the east from 2:00 to 3:00 is Banded Mountain, composed of the Banded Mountain Member of the Bonanza King Formation. The chevron pattern could easily be mistaken for folding; however, it is the result of erosion of a sequence of rocks dipping toward Yucca Flat. Check it out on the return from Stop 2-6.

1.6/43.9 Road goes down over Yucca Fault Scarp. The displacement on the fault at this location is natural and not the result of tests.

0.5/44.4 Road to right goes to Sedan Crater (Stop 2-5).

0.3/44.7 Stop 2-5: Sedan Crater

The Atomic Energy Commission conducted the nuclear excavation experiment, Sedan (Figure 2-5), on July 6, 1962. The detonation was part of the commission’s Plowshare Program to develop peaceful uses for nuclear explosives. Sedan was the second in the Plowshare series; the first test, Gnome, was fired on December 10, 1961.

Sedan was a 104-kiloton nuclear device detonated 192 m [635 ft] underground to develop technology to use nuclear energy for earth-moving projects. The explosion displaced about 12 million tons of earth, creating a crater 390 m [1,280 ft] in diameter and 98 m [320 ft] deep. The force of the detonation released seismic energy equivalent to a M = 4.75 earthquake.

In June 1963, employees of the Lawrence Radiation Laboratory (today named the Lawrence Livermore National Laboratory) and Reynolds Electrical & Engineering Company, Inc. winched a drilling rig to the floor of the crater on a ramp of metal matting 168 m [550 ft] long. The rig was used to determine the depth of the fractured area and to penetrate ground zero to collect additional scientific data.

Return to Groom Lake highway.

0.5/45.8 Turn left on 10-02 Road.

2.0/47.8 At 3:00 is the site of a former Environmental Protection Agency experimental 14.6-hectare [36-acre] dairy farm that was developed and operated between 1965 and 1981. This extensive research program studied the passage of airborne radionuclides through the soil–forage–cow–milk food chain. Studies here included the use of four fistulated steers (animals with a surgical opening in their sides) to sample the forage as they ranged over parts of the test site. The uptake of pollutants in horses, pigs, goats, chickens, and farm-grown vegetables was also studied (DOE, 2009).

0.7/48.5 Keep to left.

0.9/47.4 Stay on paved road.

0.3/49.9 Stop 2-6: Spent Fuel Test-Climax

To the north is Oak Springs Mesa. The **head frame** halfway up the slope is at the Climax Mine. This tungsten mine was opened in 1940. It was operational until the 1950s when the Atomic Energy Commission bought the mineral rights.

At this stop (Figure 2-5), the ground beneath us is granite (**quartz monzonite** and **granodiorite**). This was the site of several underground effects tests and the Spent Fuel Test-Climax.

In this immediate part of Nevada, the only Mesozoic rocks are small granitic intrusions. In addition to the Climax stock, the Gold Meadows stock occurs about 13.0 km [8.0 mi] to the west and the Twin Ridge intrusive occurs about 6.5 km [4 mi] to the southeast (Maldonado, 1977). The ages of the Climax and Gold Meadow stocks are 101 mya and 93.6 mya, respectively; granitic stocks represent a period of crustal thickening and heating that probably culminated in Cretaceous time. At this location, the granitic body metamorphosed the surrounding Paleozoic rocks. The Climax Mine is located in this surrounding **aureole**. This area is also known as the Hard Hat/Pile Driver Complex after two of the tests conducted here.

The Spent Fuel Test-Climax was conducted from 1978 to 1983 (Patrick, 1986). It was the first experiment conducted to study the actual underground emplacement of spent fuel (Figure 2-6). Unlike proposed designs for a potential repository at Yucca Mountain, the fuel was emplaced remotely in alternate vertical drill holes in the floor of the drift at a depth of 467 m [1,400 ft]. Actual fuel canisters were separated by holes with electrical heaters. The fuel was loaded in canisters at the engine maintenance and disassembly facility we passed earlier in Jackass Flat. The fuel canisters were stored for 3 years, then retrieved, repackaged, and shipped to

DOE's Idaho National Laboratory near Idaho Falls, Idaho. To test retrievability, the fuel elements were moved between holes during the test period.

The mine shaft was constructed for two earlier nuclear tests: Hard Hat and Pile Driver. These tests investigated effects of a nuclear detonation in a granite rock formation.

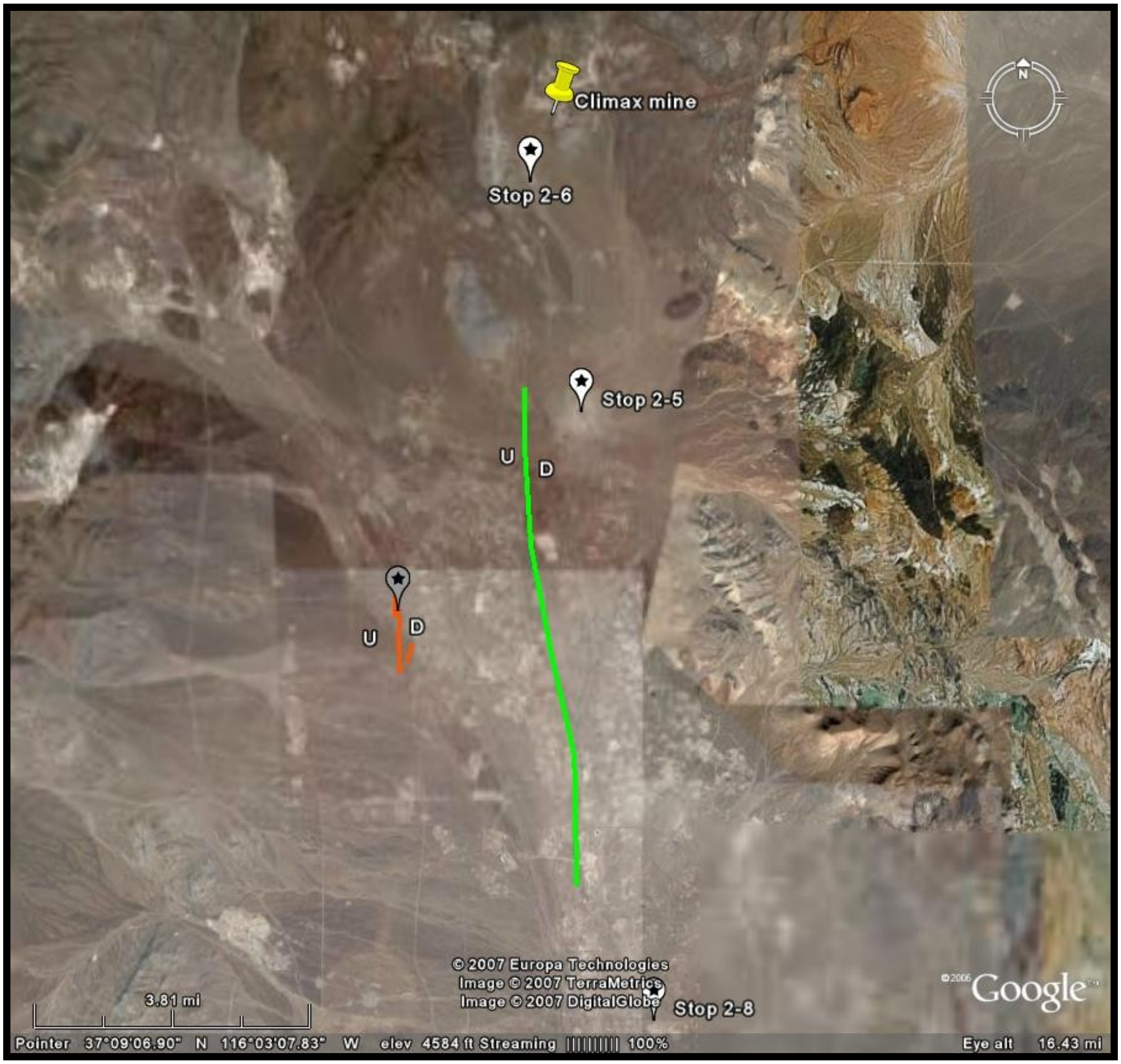

Figure 2-5. Locations of Stops 2-5, 2-6, 2-7 (marked but not labeled), and 2-8 in Yucca Flat. The green line marks the approximate location of the Yucca Fault. The orange lines mark the location of the surface traces of the Carpetbag Fault near Stop 2-7. U indicates the upthrown side of the faults, D the downthrown sides. The Climax Mine was a pre-Nevada test site tungsten mine.

Figure 2-6. View down main drift of the Spent Fuel Test-Climax Underground Facility. Remote controlled fuel handler is at far end of the drift. Spent fuel was emplaced beneath 2,268-kg [5,000-lb] circular concrete plugs in steel lined-hole in the floor of the drift. (Photo courtesy of the National Nuclear Security Administration/Nevada Site Operations <http://www.nv.doe.gov/library/photos/photodetails.aspz?ID=1299> 22 February 2008.)

Return to Groom Lake Road. Check the view of Banded Mountain from this vantage point. See the west dip of the stratigraphic units.

3.2/53.1 Turn right onto Groom Lake Road.

2.7/55.8 Take 02-07 Road to right.

2.0/57.8 Junction of Rainier Mesa Road and 02-07 Road. Turn left.

1.9/59.7 Turn right on 02-02 Road.

0.8/60.5 Carpetbag Fault scarp ahead.

0.1/60.6 Stop 2-7: Carpetbag Fault

Geology

This stop allows us to discuss the geology of Yucca Flat, the most extensively studied basin within the Basin and Range Province. Initial geological and geophysical studies supported the Nuclear Test Program. Later studies supported the Environmental Management Program. Yucca Flat is bordered on the west side by Mine Mountain and the Eleana Range, on the north by Rainier Mesa and the southern end of the Belted Range, on the east by the Half Pint Range, and on the south by the C.P. Hills. Yucca Flat is approximately 34.4 km [21.4 mi] long in a north-south direction and 16.4 km [10.2 mi] wide in the east-west direction. The elevation ranges from approximately 1,190 m [3,900 ft] at Yucca Playa to about 1,400 m [4,600 ft] at the northern end near the EPA farm.

Exploration of the Yucca Flat subsurface has included hundreds of drill holes, many of which were extensively sampled. Physical and chemical property measurements (i.e., bulk density, grain density, water, and carbonate content) were performed on thousands of samples. In hole photography and geophysical measurements of sonic, density, magnetic, and electrical properties were also made in holes drilled over the last 30 or more years. A wide variety of geophysical surveys including seismic, magnetic, electrical, and gravity have been conducted in many areas of Yucca Flat. Northern Yucca Flat consists of two basins with a north-south buried ridge of Paleozoic rock separating them. This ridge was first identified by a gravity survey and is sometimes referred to as the gravity high or the Paleozoic high. The eastern basin is the larger and deeper of the two. The base of the Yucca Flat basin is the Miocene tuffs—Paleozoic rock contact (i.e., this is a Tertiary-Quaternary basin). Starting at its eastern boundary, the bottom of the basin deepens to the west. In addition to the eastward dip of the Paleozoic rocks, as seen in Banded Mountain, across the valley there are several west-dipping normal faults that further contribute to westward-increasing basin depth. The deepest part of the basin, based on geophysical data modeling, is estimated to be about 2,500 m [8,200 ft] (Asch, et al., 2009, Figure 7). This deep point is on the east side of the Yucca fault over the hanging wall block. The Yucca fault is an east-dipping fault with a vertical displacement of about 800 m [2,625 ft]. It extends nearly the entire length of Yucca Flat. To the north it has Holocene offset at the surface that we crossed going to Stops 2-5 and 2-6. The prominence of the surface displacement decreases to the south. We will cross it again going to Stop 2-8. On the west side of the Yucca fault, over the footwall block, the basin shallows but deepens again between the Yucca fault and the Carpetbag fault into a subbasin. East of this stop a secondary deep point, over the Carpetbag fault hanging wall block, is present. Like the Yucca fault, the Carpetbag fault is an east-dipping normal fault. However, unlike the Yucca fault, there was no surface indication of its presence until after the Carpetbag test. Its surface expression is the north-south-trending scarp that the road crosses at this stop. The trenches to the north show the presence of the fault to be within a few tens of millimeters (several inches) of the surface. To the south of this stop multiple **ramp structures** transfer displacement from one section of the fault to another, mimicking ramp structures seen at Yucca Mountain toward the southern end of the Solitario Canyon fault and on Jet Ridge to the west (Ferrill and Morris, 2001; Ferrill, et al., 1999).

The eastern border of the smaller western basin is about 1.5 km [2.4 mi] to the west of this stop (Phelps, et al., 1999, Figure 9b). Based on the date from Phelps, et al. (1999, Figure 9a), the basin is estimated to be between 500 and 600 m [1,640 and 1,970 ft] deep.

In a broad sense, the stratigraphy of Yucca Flat is similar to Crater Flat. Beneath the surface, with increasing depth, is alluvium, Miocene tuffs, and Paleozoic and Neoproterozoic basement. There are differences in details. While the alluvium becomes finer and more homogeneous to the south, the composition of the alluvium in northern Yucca Flat and around its boundaries is quite variable, reflecting diverse source areas (Wagoner and McKague, 1986). In this part of northern Yucca Flat, the alluvium has a story to tell. In the subbasin between the Carpetbag and Yucca faults, the three types of alluvium can be recognized. The oldest alluvium, above the contact with the underlying Miocene tuffs, is composed of tuffaceous material (>95 percent tuff clasts; <5 percent Paleozoic clasts) and is present in the deeper part of the basin. In the mixed alluvium, above the tuffaceous alluvium, Paleozoic clasts are predominant. Cobbles and boulders of Paleozoic carbonates are visible in photographs (still and movies) of the mixed alluvium taken in nearby large diameter drill holes and indicate the gravity high was a nearby source of some of the alluvium. Other sources of alluvium (e.g., Rainier Mesa) were more distant. In the upper few hundred meters of alluvium, clasts of yellow brown Eleana formation become noticeable in drill hole samples. This alluvial sequence (i.e., tuffaceous, mixed, and Eleana bearing) can be interpreted as follows. The tuffaceous alluvium represents erosion of the Miocene tuffs that cover surrounding Paleozoic hills, including the now-buried gravity high. As the tuff cover was eroded away, perhaps in combination with faulting, the gradually exposed underlying Paleozoic rocks became the major source of detritus for the mixed alluvium. There are few, if any, Eleana-type clasts in the mixed alluvium below a depth of approximately 183 m [600 ft], suggesting the Paleozoic ridge may have blocked the eastward transport of Eleana clasts from the Eleana Range the ridge was exposed later. As noted previously, the upper sequence of alluvium contains noticeable amounts of Eleana clasts. Looking west from this stop, it is obvious that Eleana material can now be transported relatively unimpeded to this stop. The presence of the Eleana clasts east of the gravity high suggest it was topped as the western basin filled or there was a change in the drainage pattern from the north end of Eleana Range, forcing it in a more eastward direction. The modern-day drainage pattern through this area is from the Rainier Mesa area to the northwest (see Figure 2-5).

It is clear that the surface developed on the Paleozoic rocks before deposition of the Miocene tuffs was not flat. On the west side of the Eleana hills, in Area 12 (Rainier Mesa area to northwest of this stop), topographic relief on the Paleozoic surface is readily visible. The relief (i.e., difference in elevation) of the basement-Miocene tuff contact on the east and west sides of the Carpetbag fault may in part be the result of preexisting topography, present prior to the initiation of basin and range faulting about 17 mya.

The thick sequence Eocene to Miocene continental clastic rocks (Stops 1-9, 3-1, and 3-6) that are present beneath the Miocene tuffs south of Yucca Mountain and along the southern edge of Frenchman Flat, is replaced beneath and around Yucca Flat by a relatively thin {61 m [200 ft]} accumulation of Paleozoic derived colluvium.

While some of the same tuff units present beneath Crater Flat are present beneath Yucca Flat, in Yucca Flat bedded and nonwelded tuffs are more common and welded units are thinner and less common. Some of the tuffs beneath Yucca Flat represent the distal ends of ash flows and air falls that are present beneath Crater Flat and at Yucca Mountain as welded ash flows. The Paintbrush tuff beneath Yucca Flat is predominantly a bedded nonwelded tuff, vastly different from the welded Paintbrush tuff seen earlier at Stop 2-1. The volcanic sources of some of the deepest and oldest tuffs in Yucca Flat were well to the north of the southwestern Nevada volcanic field. Their distribution suggests they may be limited to filling valleys and depressions on the Paleozoic surface.

The Paleozoic and Neoproterozoic basement rocks underlying the Tertiary-Quaternary Yucca Flat basin are composed of rocks representative of the lower aquitard, lower carbonate aquifer, upper aquitard (Eleana Formation), and the upper carbonate aquifer (Table 0-1). Interpretation of geological (Cole and Cashman, 1999) and geophysical (Asch, et al., 2009) data shows the basement rocks are as complexly folded and faulted beneath Yucca Flat as seen elsewhere in southern Nevada.

Nevada Test Site Activities

Nuclear testing was first conducted underground in 1956 as a means of reducing radioactivity in the atmosphere (Carothers, 1995). The 1963 Nuclear Test Ban Treaty required signatories to prohibit, prevent, and not to carry out any nuclear test explosion in the atmosphere, space, or underwater or in any other environment (underground) that would allow radioactive debris to leave the territorial limits of the state conducting the explosion. The Charter of DOE's Containment Evaluation Panel defines successful containment as a test that results in no radioactivity detected offsite (Nevada Test Site) as measured by normal monitoring equipment and no unanticipated release of radioactivity within the first 24-hour period following the test. After 1963, all tests were conducted underground (DOE, 2000). Tests with anticipated release of radioactivity (e.g., plowshare cratering experiments) were permitted by treaty.

Unanticipated releases of radioactivity from underground tests could be attributed to three causes: (i) inadequate understanding of the explosion phenomenology, (ii) failure of the natural barrier, and (iii) failure of the engineering barrier. Releases of the first type took place in the very early days of testing and were eliminated with experience. Perhaps a half dozen releases can be largely attributed to failure of the natural barrier; the largest number of releases could be attributed to failures of the engineering barrier. This included a number of paths, such as the **stemming in the hole**, cables and cable bundles, and downhole diagnostic equipment or some combination of these features.

Return to Rainier Mesa Road; turn right.

5.4/66.0 BJ Wye.

The southeast limb of Syncline Ridge is at 2:00.

In the Eleana Range, the west side of the valley is a syncline that was formed as a result of Mesozoic compressional deformation. The areas both east and west of Syncline Ridge were explored to determine their suitability for a nuclear waste repository site. The Mississippian (354–323 mya) Eleana Formation is an **argillite** (**mudstone**) with lesser sandstone and conglomerate units. Before drilling and geophysical exploration, it was thought that the site would be lithologically homogeneous, unfaulted,and suitable for a potential repository. However, drilling revealed the area to be geologically very complex with folding and faulting (Sweeney, 1986), such as was seen at Stops 1-1 and 1-5. The complexities were determined to be too great to be a suitable repository site. In addition, the nearby nuclear testing would have been an added complication.

1.1/67.1 Turn left.

0.1/67.2 Yucca Fault Scarp.

We are going down over the scarp of the Yucca Fault. Here the displacement was induced by **underground testing**. This fault has natural Holocene movement at its north end. This general area was used by Los Alamos National Laboratory for their tests and was referred to as the Area 3 Sandpile. It was a favorite test area because of the homogeneous geology and well-known physical properties of the alluvium. This would be expected, as much of the alluvial material has been transported down Yucca Valley and subject to mixing, attenuation, and sorting of clast size.

1.2/68.4 Turn right into parking area.

0.1/68.5 Stop 2-8: Area 3 Waste Management Site

This site is used to bury waste generated on the site as a result of the early atmospheric testing. The waste is placed in craters formed by collapse of the overlying earth into cavities formed as a result of an underground explosion. The waste is then covered with native material (alluvium).

Proceed back to Mercury Highway and turn left.

14.3/82.8 Cane Spring Road to right.

3.1/85.9 Turn left on 5-07 Road.

0.8/86.7 Just ahead we cross the Old Indian Springs stagecoach road going in a northwest-southeast direction across the road. In the Massachusetts Mountains from 8:00 to 9:00, the dark reentrant is a vitrophyre lava of the Wahmonie Formation onlapped by the Topopah Spring Member of the Paintbrush Group. The caldera for the Wahmonie tuffs is in the hills behind us at 6:00. It is the smallest Miocene volcano in the southwestern Nevada volcanic field.

4.2/90.9 Cambric experiment (36° 48' 15.84" N; 115° 57' 04.47" W).

The Cambric event site is at 3:00 (Figure 2-7). Cambric was a low-yield test conducted in the 1960s in saturated alluvium. Starting 10 years after the test, groundwater adjacent to the test was pumped steadily at rates between 1,650 and 3,280 m^3/day [435,883 and 866,484 gal/day] from a well 91 m [300 ft] from Cambric (Hoffman, et al., 1977). Pumping lasted 16 years. The well was pumped for more than 2 years before tritium was detected in the discharge. Ultimately, in addition to tritium, Kr-85, I-129, C-14, and Cl-36 were detected, with Ru-106 and Tc-99 occasionally detected.

The water pumped from the Cambric site was discharged into a ditch that conveyed the water toward Frenchman Flat Playa to the southeast (Figure 2-7). A second study was an outgrowth of this discharge (Thompson, et al., 2006). The ditch carrying water away from the Cambric radionuclide migration study offered an opportunity to quantitatively study the infiltration process in alluvium in an arid climate. Groundwater containing H-3, C-14, Cl-36, and Kr-85 with lesser amounts of I-129, Ru-106, and Tc-99 was pumped nearly continuously for 14 years. About one-third of the water pumped at the wellhead was lost over the 1,000-m [3,280-ft] length of the ditch, predominantly by infiltration. This loss was estimated to be approximately 2 m^3/day/m [21.4 ft^3/day/ft] of ditch length (Ross and Wheatcraft, 1994). A monitoring well, located 500 m [1,640 ft] from the pumped well and 106 m [348 ft] north of the ditch, provided an opportunity to

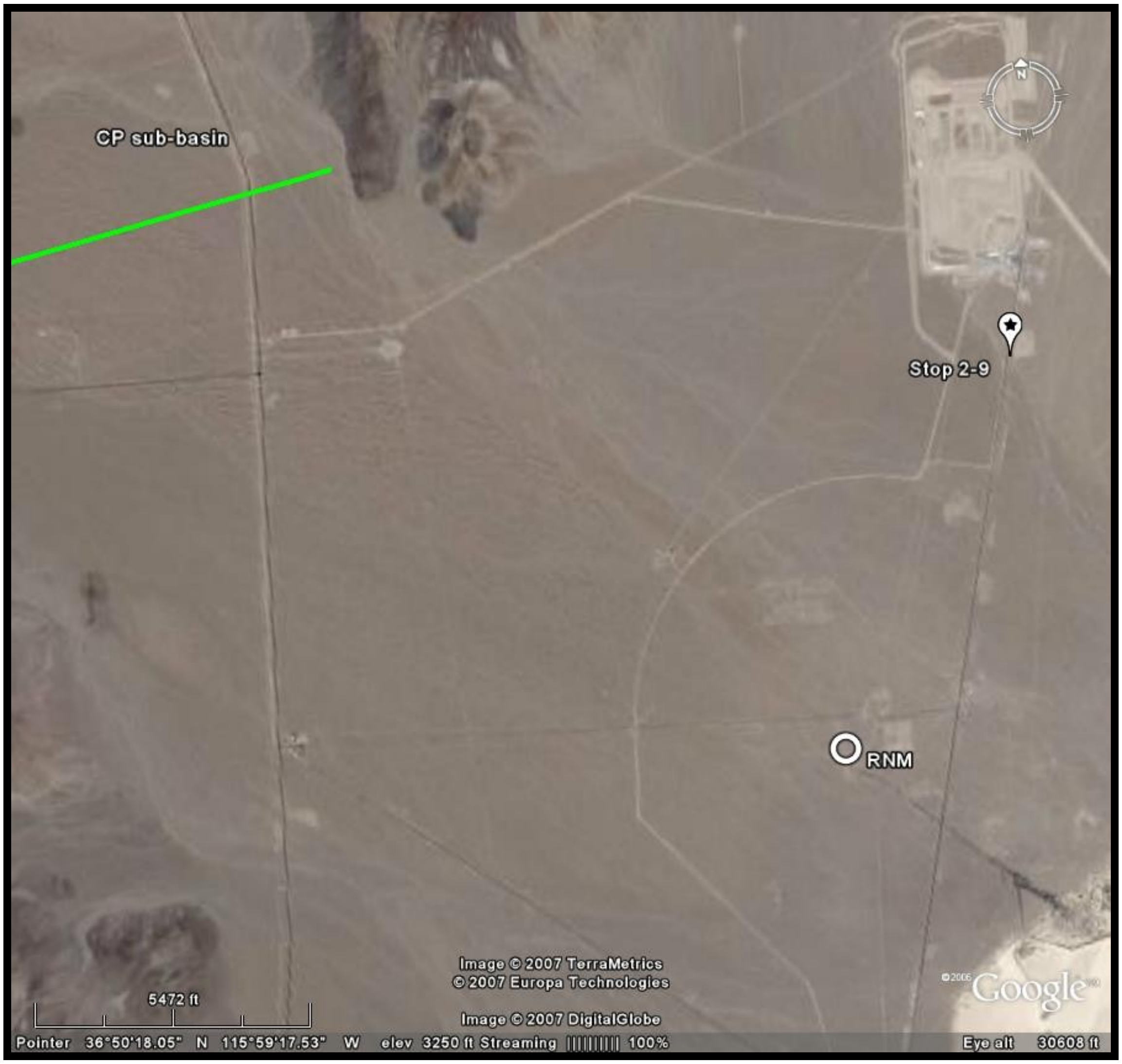

Figure 2-7. Location of Stop 2-9 south of the Area 5 waste management site. The location of the Cambric Radionuclide Migration (RNM) experiment is shown by the circle. The ditch that was used to transport the pumped water from the experiment to the Frenchman Flat Playa is shown by the thin dark line of vegetation extending southeast from the site. The green line in the northwest quadrant of the image, between Frenchman Flat and the CP subbasin, marks a possible location of the northern boundary of the Pre-Miocene extensional basin described at Stops 1-9 and 3-1.

sample the saturated zone at this location. The unsaturated zone in this area is 220 m [722 ft] thick. Between 1991 and 1993, tritium was detected in the monitoring well. This was interpreted as indicating a 13- to 15-year transit time for the water to move vertically to the water table from the ditch, then horizontally to the monitoring well (Thompson, et al., 2006). Geochemical studies of radioactive and stable **isotopes** suggest (i) the transit time for the vertical infiltration from the ditch to the water tables was 3.5 to 5.5 years; (ii) as much as 60 percent of the water extracted from the monitoring well in 2000 had been recycled, especially from that part of the ditch closest to the original pumping well; (iii) larger than expected decreases (considering decay) in tritium and Kr-85 between the amounts in the original pumped well and the monitoring well were attributed to losses to the gas phase during transport; and (iv) a similar decrease in C-14 was attributed to retardation or sorption by calcite (Thompson, et al., 2006).

0.3/91.2 Left turn on 05-01 Road.

3.3/94.5 Stop 2-9: Area 5 Radioactive Nuclear Waste Management Site

The facility ahead of us is used for low-level waste disposal from defense-related operations at and beyond the test site. The Area 5 Radioactive Waste Management Site is located in a 296-ha [732-acre] Radioactive Waste Management Zone and has been in use since 1961. Waste is stored in land-filled trenches, pits, and shallow boreholes.

Return south on the 05-01 Road.

2.2/96.7 At 11:00 is the Spill Test Facility.

The Spill Test Facility is used for releasing volatile hazardous materials and measuring their behavior in outdoor conditions. It is a one-of-a-kind facility and has been in use since 1986 as a place to safely conduct experiments associated with the handling, shipping, and storage of liquefied gaseous fuels and other hazardous fluids. Tests are carried out only when the weather conditions are favorable. This facility is available to private and public organizations on a user-fee basis.

0.5/97.2 Frenchman Flat Playa is from 8:00 to 10:00.

This playa was used for many of the early atmospheric tests.

> "Between January 27, 1951 and March 25, 1968, fourteen atmospheric and five underground tests were detonated at Frenchman Flat. The 320-square-kilometer (123-square-mile) dry lake bed is one of three major closed desert valley basins at the Nevada Test Site, the others being Yucca and Jackass Flats. From 1953 to 1958, reinforced structures were exposed to some of the nuclear blasts and accompanying overpressures. Among the items exposed to the blasts were French- and German-designed shelters, a Mosler safe, a railroad bridge, butler buildings (hangers), a man-made pine tree forest planted in concrete blocks, railroad rolling stock, tanks, and other items of military equipment." (DOE, 2006b)

3.6/100.8 Ditch, as indicated by line of dead vegetation, from Cambric experiment crossed beneath road (Figure 2-7).

1.4/102.2 Rock Valley at 2:30.

Quaternary fault scarps of the Rock Valley fault have been recognized to the left of Hemple Hill (the light-colored hill at 3:00). The fault zone crosses the road at approximately this point and continues northeast to the foot of Ranger Mountains (8:30 to 9:00). Pump Station No. 4 is just off the road at 3:00.

Facing south down the 05-05 road at 10:00 in the near distance {1.6 to 3 km [1 to 2 mi]} are hills of Tertiary gravels and the tuffaceous sedimentary Rocks of Pavits Spring. Light-colored lacustrine limestones of the underlying Horse Spring Formation are seen from 1:00 to 2:00 where they onlap or are faulted against the Eureka Quartzite. These rocks correlate with the pre-basin-and-range sequence of Fridrich, et al. (2009), which will be discussed in more detail on Day 3. Horse Spring contains a **biotite** from a tuff bed dated 29.3 mya (Marvin, et al., 1970). The source of the tuff may have been the very large Indian Peak caldera of similar age located about 240 km [150 mi] northeast on the Nevada-Utah border. The Horse Spring Formation and the Rocks of Pavits Spring were deposited in continental basins and represent the earliest stage of extensional deformation in this part of Nevada. The rocks were deposited in basin(s) that extended at least as far west as northern Death Valley—a distance of approximately 100 km [62 mi]—and south 64 km [40 mi] to the Amargosa Desert area (Stop 3-1). In this area, the northern boundary of the basin occurred between here and Yucca Flat (Figure 2-7) where geophysical surveys (Phelps and Graham, 2002) show a boundary between the deeper Frenchman Flat basin and the shallower CP basin. In the Yucca Mountain area, these older Tertiary gravels compose the deeper part of the alluvial aquifer south of Yucca Mountain. As described at Stop 2-7, the time equivalent rocks beneath Yucca Flat are represented by colluvium, with increasing ash fall material mixed near the top of the colluvium. These deposits are commonly thin <30 m [100 ft] and most likely represent the weathered surface of the Earth immediately prior to deposition of the tuffs.

3.0/105.2 At junction with Mercury Highway, turn left.

2.5/107.7 Road goes through Checkpoint Pass with Silurian and Devonian carbonates on both sides of the road.

0.8/108.5 Checkpoint Pass Guard Station 200.

Starting on the evening preceding a test and on the day of a test, no one could proceed beyond this point without a muster pass. This allowed security and safety personal to monitor those in the forward area (i.e., beyond this point).

1.7/119.2 Red Mountain is to the right between 3:00 and 6:00.

The band of lighter colored rock near the top of the mountain and dipping to the east is the Ordovician Eureka Quartzite; the rocks below it are limestones of the Pogonip Group and above it is the Ely Spring dolomite (Table 0-2). All these rocks are part of the regional carbonate aquifer. To the left between 7:00 and 8:00 is Mercury Ridge underlain by Devonian limestones.

Mercury, Nevada

Mercury was established in 1953 to support a continental nuclear test program. Prior to the initiation of testing in Nevada, all testing was carried out at the Pacific Proving Grounds. During its heyday, Mercury had a day population of several thousand, with most of the workers commuting by bus from Las Vegas, Nevada. Mercury has offices, warehouses, medical facilities, housing, recreational facilities, and a cafeteria/restaurant. On the west side of the highway, 1.8 km [1.1 mi] north of Gate 100, is the U.S. Geological Survey Data Center and Core Library where core and cutting samples taken from boreholes drilled in support of the nuclear test program are stored. The facility also has a reference library with reports, maps, aerial photos, downhole video tapes, and geophysical logs. Initially, the samples from

Yucca Mountain were stored here, but they were later moved to the Sample Management Facility in Area 25 (see description on first half of Day 2).

After stopping at Gate 100 to return temporary badges, proceed along US Highway 95 to Amargosa City, and turn left on NV 373. Longstreet Inn is 26 km [16 mi] south.

Longstreet Inn (36° 24' 44.87" N; 116° 25' 24.15" W).

END OF DAY 2.

Blank Page

DAY 3

Leave Longstreet Inn, Amargosa Valley, Nevada. Turn right on NV 373.

0.0/0.0 California–Nevada state line.

0.6/0.6 Turn right onto Clay Road.

0.8/1.4 Follow road across Amargosa River (indicated by the vegetation). After about 0.5 mile, turn right and follow road to BLM #1 on right side of road.

2.2/3.6 Stop 3-1: Inyo County Research Wells BLM #1 and #1A

This stop is along the southwest edge of the Amargosa basin, east of the southern end of the Funeral Mountains (12:00), north of Bat Mountain (9:00–10:00).

The Inyo County Research wells BLM #1, #1A, and #2 (Figures 3-1 and 3-2) are part of Inyo County, California's Death Valley Lower Carbonate Aquifer Monitoring program (Inyo County Yucca Mountain Repository Assessment Program, 2005). The Inyo County scientific drilling program was started in 2002 and reported on in 2003 (Jensen, et al., 2003), 2004 (Jensen, et al., 2004), and 2005 (Bredehoeft, et al., 2005). Drill holes for BLM #1 and BLM #2 are north and northwest of Bat Mountain (Figure 3-2) and are downgradient from the potential Yucca Mountain repository. They were drilled to determine the depth to the top of the Regional Carbonate Aquifer (Inyo County Research Wells BLM #1 and #1A, 2005). This program was funded by a research grant from DOE to determine (i) whether a flow path exists in the Paleozoic Carbonate Aquifer connecting the Amargosa and the Death Valley Basins, (ii) how the aquifer water may transverse the southern Funeral Mountains, and (iii) whether there is a hydraulic connection between the potential repository site at Yucca Mountain and the springs in Death Valley. During the drilling of these wells, the stratigraphy was described by geologists of the U.S. Geological Survey acting as agents for Inyo County. BLM #1 was drilled to a total depth of 889 m [2,900 ft], with the Regional Carbonate Aquifer encountered at 744 m [2,440 ft] (Bredehoeft, et al., 2005). Older Tertiary sediments were encountered above the Paleozoic rocks. Borehole BLM #1A was subsequently drilled to a depth of 192 m [630 ft]. Its purpose was to establish a water level in the alluvium aquifer, which proved to be at a depth of 186.8 m [613 ft]. BLM #2, to the northwest of BLM #1, was completed at a total depth of 823 m [2,700 ft] and bottomed in older Tertiary sediments. The BLM #1 well is aligned with the northeast end of Bat Mountain (Figure 3-1), and the BLM #2 well is located to the northwest in alignment with the southern end of the Funeral Mountains. The Bat Mountain fault, a normal southeast-dipping fault, passes between Bat Mountain and the southern end of the Funeral Range. Figure 3-2 shows the lithologic correlation between the wells, where the Kelley's Well Limestone and the top of the Amargosa Valley Formation are deeper in BLM #2 than in BLM #1, suggesting a fault passes between them.

The stratigraphy of the older Tertiary sedimentary rocks around Yucca Mountain (Stops 1-5, 1-8, and 2-9) is important in determining age and extent of deposition, styles of deposition, and assignment of chronologic order to develop a regional tectonic history, especially for the last 11 to 12 million years. In addition, these rocks are part of the valley fill aquifer south of Yucca Mountain (Stop 1-5).

Fridrich, et al. (2009) introduced a new regional Cenozoic Tectono-stratigraphy scheme for the Southern Funeral Mountain area. This new classification is based on stratigraphy and new age dates. His classification recognizes three sequences of Cenozoic deposits: pre-basin-range, syn-basin-range, and post-basin-range. The earliest, the pre-basin-range sequence, was deposited from the late Eocene [(>40 million years ago (mya)] to the early Miocene (≈19 mya), during the initial period of extension in southern Nevada. Alluvial conglomerates and lacustrine limestones and **marl**s (limestones and mud) are characteristic of the pre-basin-range stratigraphic sequence. This sequence of rocks was deposited over the older Paleozoic rocks as shown in Figure 3-2 (BLM #1). In that figure, the part of the stratigraphic columns in BLM #1 and BLM #2, below the Kelly's Well limestone, labeled Amargosa Valley Formation, is part of the pre-basin-range sequence, as are the rocks below the same limestone unit on Bat Mountain.

In the southern Funeral Mountains the pre-basin-range and syn-basin-range sequences are separated by approximately a 3-million-year period of nondeposition between 19 and 16 mya. The end of this period of nondeposition occurred about 0.75 million years before the start of the extensive Miocene volcanism in southern Nevada (Sawyer, et al., 1994). That extensive period of volcanism in the Yucca Mountain region was concurrent with the deposition of the syn-basin-range sequence in this area. Some of the air fall tuffs in the syn-basin-range sequence probably came from those volcanic eruptions of calderas immediately north of Yucca Mountain. The oldest rocks in the syn-basin-range sequence are about 16 mya. However, the deposits at the top (youngest) of the sequence range in age from about 6–7 mya in this area to 2 mya in the Furnace Creek area (Stops 3-6-and 3-7) (Fridrich, et al., 2009). This reflects the progressive westward movement of tectonism in the Death Valley region with time. At Bat Mountain, the base of the syn-basin-range sequence is the Kelly's Well limestone. In Figure 3-2, this sequence corresponds to the Kelly's Well limestone and the deposits above, except very near the top of the wells. The alluvium there is part of the post-basin-range sequence. The rocks in the syn-basin-range sequence are variable and include alluvial conglomerates, volcanic ash falls, and basalt lava flows, lake beds, playa deposits, and giant-block breccias. The presence of locally derived metamorphic clasts is indicative of uplift and denudation (i.e., ongoing vertical deformation) during this period. The strata are commonly highly tilted, and unconformities are common along the highway into Death Valley. These rocks represent a time when the rate of deformation was (is) (see Stop 3-8) high and largely vertical. Formation names, used on existing geologic maps of the Death Valley region, that are included in this syn-basin-range sequence, are, from oldest to youngest, Bat Mountain, Artist Drive, Greenwater volcanics, Furnace Creek, and Funeral formations.

The age of the post-basin-range sequence basal deposits is from 6–7 mya to 2 mya. (Fridrich, et al., 2009). The youngest are being deposited today. These deposits are predominantly colluvium, with some spring and playa deposits. Compared with the syn-basin-range deposits they are thinner and less deformed with rare unconformities. The post-basin-range sequence rocks are representative of a time, following the period of maximum deformation, where the tectonic and depositional rates had (have) decreased and the style of deformation changed from largely vertical to largely horizontal (Fridrich, et al., 2009).

Figure 3-1. Site of Inyo County Research Well BLM #1. In background, Bat Mountain (left) separates from southern end of Funeral Mountains by the Bat Mountain normal fault (as indicated by white arrows).

The waters in the springs (Stop 3-7) in Death Valley have the characteristic geochemical signature of the Carbonate Aquifer (see Stop 2-2—Water Geochemistry). One goal of this drilling program is to determine the path the groundwater follows from the Amargosa Desert to the springs in the Death Valley area. One possibility is that the flow path is around the southeastern end of Bat Mountain and the Funeral Range and then northwest along Furnace Creek Wash, perhaps controlled by the Furnace Creek Fault. The second theory is that the flow path passes under the Funeral Mountains in the Regional Carbonate Aquifer rocks. These two wells were located in part to test the second theory. Based on surface mapping, Bredehoeft, et al., (2005) propose the water flows through the Regional Carbonate Aquifer over a spillway-like structure in the Regional Clastic Aquitard beneath the Funeral Mountains. Stratigraphic data from the wells suggest this is a viable theory. However, two alternative models have been proposed for the hydrologic pathway beneath the Funeral Mountains. The difference between the models is in the assumed dips of faults in the Funeral Range. Steeper faults would provide a thicker section of the carbonate aquifer, which would be available for the flow path (Bredehoeft, et al., 2005). Conversely, shallow faults would provide a thinner and more restricted path through the Lower Clastic Aquitard for the water.

Return to CA 127. Go north.

0.0/0.0 California–Nevada state line.

1.8/1.8 Turn right onto Bill Copeland Memorial Highway/Spring Mountain Road.

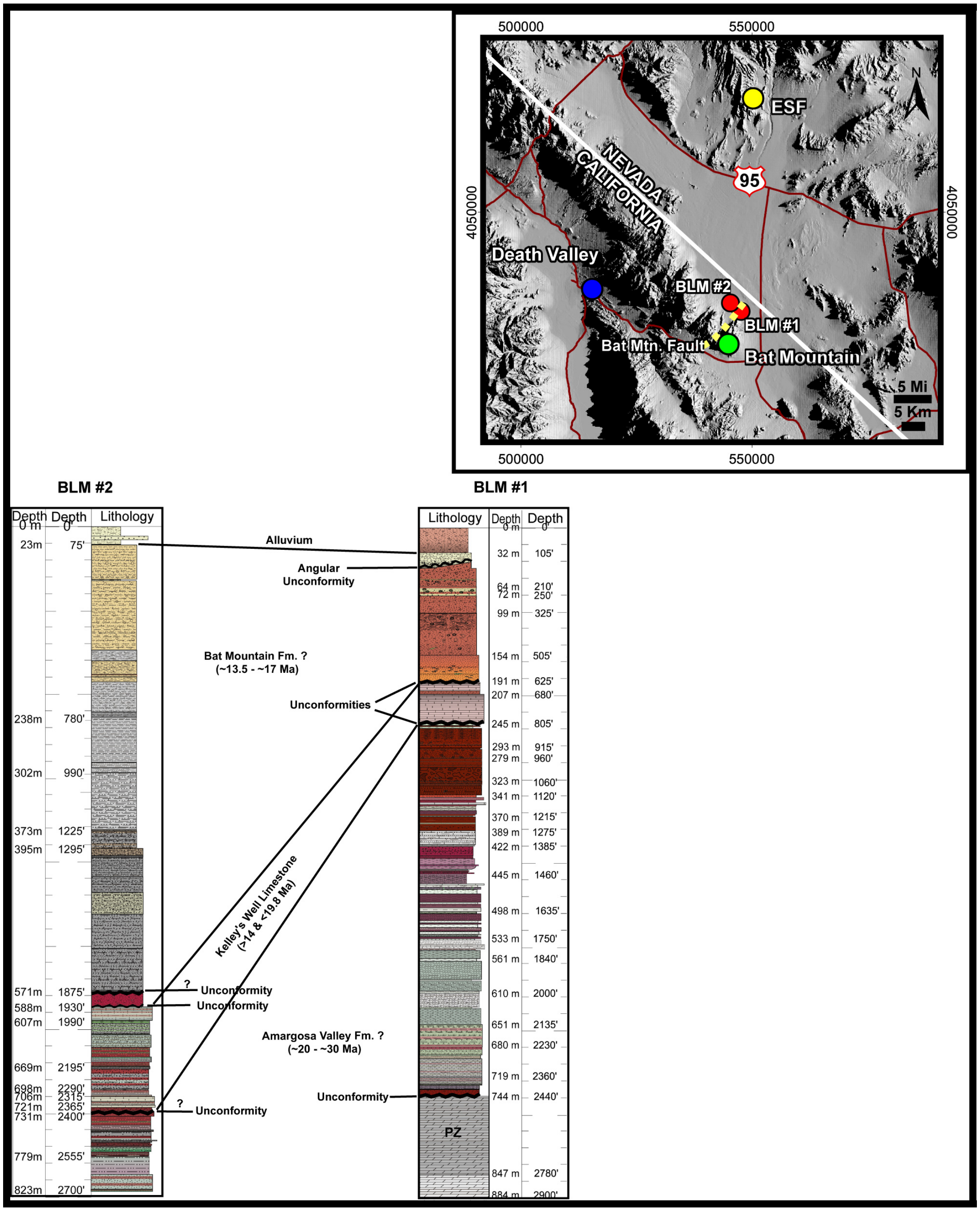

Figure 3-2. Stratigraphic columns from Inyo County Research Wells BLM #1 and BLM #2. Red dots are well locations; yellow dot is Exploratory Studies Facility. Green dot is location of Bat Mountain.

This road leads to the Ash Meadows National Wildlife Refuge. This refuge has a larger concentration of **endemic** life than any other area in the United States (U.S. Fish and Wildlife Service, 2004).

5.8/7.6 Right turn.

0.4/8.0 The spring and seeps in Ash Meadows occur along a north-south line that is more than 14 km [9 mi] long (Figure 3-3). The hills at 9:00 are composed of the highly transmissive Bonanza King Formation. In these rocks, the regional flow is from the northeast and east. Between this road and the hills, a fault or faults place those highly transmissive rocks against the relatively impermeable fine-grained clay valley fill, forcing the water to the surface along the faults or other permeable paths (Winograd and Thordarson, 1975). This fault is known as the Gravity Fault and was discussed at Stop1-5.

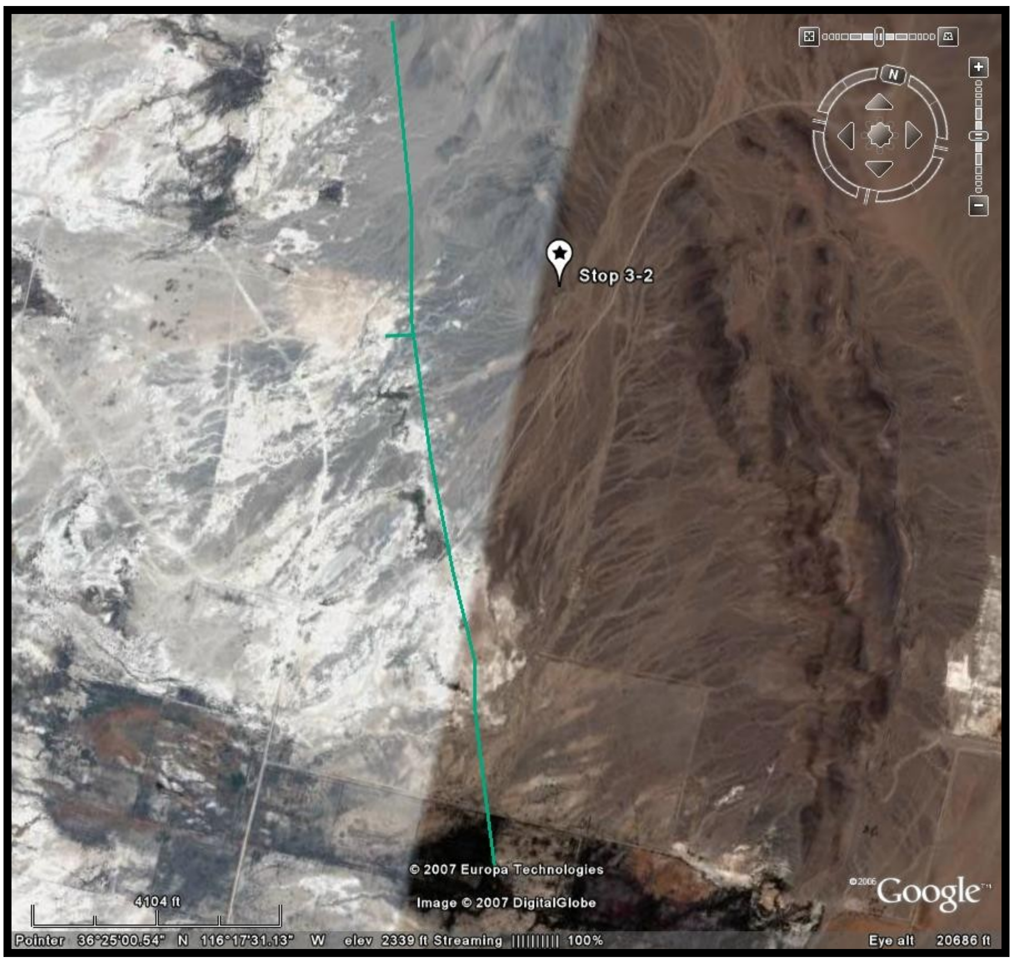

Figure 3-3. Location of Stop 3-2. Green line represents approximate location of gravity-inferred normal fault. Stop 3-2 is Devils Hole on the upthrown side of the fault. Lake beds occur across the fault on the downthrown side. Their low permeability forces the water in the regional carbonate aquifer to the surface in a line of springs.

1.3/9.3 Road junction.

0.3/9.6 At 3:00 is Point of Rocks Ridge, underlain by Bonanza King Formation.

1.1/10.7 Stop 3-2: Devils Hole (36° 25' 28.80" N; 116° 17' 28.28" W)

Devils Hole (Figure 3-4) is a collapsed cave (**karst** feature) in the Bonanza King Formation that exposes the water table. The altitude of the water table is about 719 m [2,359 ft]. The northwest-striking ridges in this area are controlled by northwest-striking folds and faults. Although the northwest-trending structures are most prominent, it is small northeast-trending faults and fractures that control the hydrology. These faults and fractures are perpendicular to the regional minimum *in-situ* stress and are more likely to be dilated. These northeast features control the location and orientation of Devils Hole and other collapsed depressions and calcite veins in the bedrock. Devils Hole is a collapsed cave approximately 22.7 × 7.6 m [75 × 25 ft] in plain view at the surface that extends more than 91 m [300 ft] below the water table. A network of passages extends at least 91.4 m [300 ft] to the northeast and includes Brown's Room, a subterranean air-filled opening that extends above the water table but not the surface. The average width of the passageway is 1.8 m [6 ft]. Below the water table, the walls of Devils Hole have a thick coating of calcite precipitated out of the groundwater. Isotopic analyses of samples from along a rock core taken perpendicularly to the walls provide paleoclimate data for the last 500,000 years. Isotopic data from water samples indicate the Bonanza King Formation upgradient of the Devils Hole area is highly permeable. The nearly vertical fractures visible above the water and in the right wall (Figure 3-4) beneath the overhang are indications of the fault along which this sinkhole developed. Additional information and references on Devils Hole are given in Appendix B.

Devils Hole is part of Death Valley National Park and the pupfish in it are protected by the National Park Service. To the southwest, Crystal Pool is present in the foreground, Bat Mountain is visible beyond the Amargosa Valley (Stop 3-1), and the southern end of the Funeral Range is seen in the distance. The Greenwater Range is present south of Bat Mountain.

Return to the cars and turn around.

1.4/12.1 Turn left at road junction.

3.6/15.7 Stop 3-3: Clinoptilolite Deposit (36° 21' 25.08" N; 116° 18' 15.55" W)

The light-green rock on the small hill to the left of the road is an altered volcanic tuff that is now predominantly **clinoptilolite** with a small amount of clay.[4] Clinoptilolite occurs in the altered Calico Hills Formation below the northern two-thirds of the repository. The southern portion of the Calico Hills Formation is **vitric** in the repository area.

Bish, et al. (2003) note that clinoptilolite is generally regarded to be important in the retardation of Sr-90 and Cs-137.

[4] McMurry, J. and J. Prikryl, x-ray diffraction data, personal communication, 2006.

Figure 3-4. Devils Hole. This feature is in part the result of dissolution along the nearly vertical fault/fractures along right side of sinkhole indicated by the arrow.

For more information on zeolites and their role at Yucca Mountain, see Appendix C.

Proceed straight ahead.

1.1/16.8 Junction with West Bell Vista road from Pahrump, Nevada.

1.4/18.2 California–Nevada state line; continue across toward Death Valley Junction, California.

1.0/19.2 Crossing Carson Slough. This is the path of surface water originating in the Ash Meadow area.

1.5/20.7 Eagle Mountain and Franklin Playa at 9:00.

Franklin Playa is one of the discharge points in the Furnace Creek–Alkali Flat groundwater system. This is the area where groundwater and surface water, when present, merge from the northwest and northeast. From here surface water, when present, flows south down the

Amargosa River then through Tecopa, California, where the river bends back to the north and flows into southern Death Valley.

The path of the groundwater is less certain. As discussed at Stop 3-1, groundwater was initially considered to flow southwest into the Furnace Creek Wash area and along the Furnace Creek fault zone into Death Valley, but a more likely path is beneath the Funeral Mountains (Bredehoeft, et al., 2005).

2.3/23.0 Death Valley Junction, California.

Death Valley Junction was named for the junction of the Tonopah and Tidewater Railroad (T and T) with the Death Valley Railroad. The T and T operated from 1902 to 1938 and was initially built to haul ore to Baker, California. The Death Valley Railroad ran southwest into the hills and hauled borate from the mines in that area. One of the locomotives for the Death Valley Railroad is on display in the Furnace Creek Campground where we will have lunch.

Becket (2008) provides information on the Death Valley Opera House.

Turn right onto CA 127.

0.0/0.0 Turn left onto CA 190 toward Death Valley National Monument.

2.2/202 Bat Mountain is to the north at 2:00.

The Oligocene and Miocene continental clastic rocks that comprise Bat Mountain are correlative with the rocks below the Miocene tuffs in some of the Nye County Early Warning Drilling Program wells south of Yucca Mountain. Funeral Mountains are at 1:00. A normal fault separates the southeast end of the Funeral Range from Bat Mountain. Çemen, et al. (1999) proposed that the Bat Mountain extensional fault resulted from the reactivation of the older Clery thrust.

South of the same location, black basalt lava flows cap underlying, lighter colored Tertiary lake deposits (Figure 3-5). These are both within the syn-basin-range sequence.

3.9/6.1 White rocks are lake beds in the Furnace Creek formation (syn-basin-range sequence). Here they are capped by basalt lavas.

Figure 3-5. Basalt flows capping light-colored sedimentary rocks of the Furnace Creek formation in north end of Greenwater Range. Looking south from California Highway 190 about 0.3 km [0.2 mi] west of Death Valley Junction, California.

5.5/11.6 The Furnace Creek fault is in front of the Funeral Mountains at 2:00 to 4:00 (Figure 3-6).

The Furnace Creek fault zone (Figure 3-7) is a northwest-striking right lateral fault with Miocene–Pliocene movement, but is considered to be currently inactive (Machette, et. al., 2001). The fault zone bounds the southwest side of the Funeral Mountains and extends northwest from the Amargosa Desert (6:00) to the Furnace Creek Ranch area and perhaps further to the northwest (Machette, et. al., 2001). Machette, et al. (2001) consider its northwest extension to be separate from the Northern Death Valley fault zone. The Furnace Creek fault zone has an estimated 30 km [19 mi] of strike-slip displacement (Çemen and Baucke, 2005).

Right-of-way for the Death Valley Railroad is at 9:00.

2.6/14.2 Basalt outcrops on either side of the road.

Figure 3-6. Location of Stops 3-4, 3-5, and 3-6. Red line is approximate location of the Furnace Creek Wash Fault. Arrows show the relative strike-slip motion of fault.

0.7/14.9 Stop 3-4: Calcite Paleospring Feeder Veins (36° 21' 57.18" N; 116° 39' 20.28" W)

At this stop, lithified alluvium of the Furnace Creek Formation is of the syn-tectonic sequence (Figure 3-7) cut by a number of vertical calcite veins. The calcite vein systems on the hillside are the remnants of the feeder system for paleosprings above them. The alluvial material was first cemented or lithified by precipitation of calcite from the groundwater, then fractured, allowing carbonate-rich water to rise along the fractures and to precipitate calcite forming the veins. The layering in the veins suggests fracturing occurred multiple times (Figure 3-8). The difficulty in matching the calcite layers on either side of the veins indicates the complex history involved in their formation. The lithified alluvium at this stop is part of the syn-tectonic sequence (Fridrich, et al., 2009).

Although only a few miles from the head of Furnace Creek, the energy of the creek during flood stage is indicated by the size of the boulders dispersed in the creek bed (Figure 3-9). The alluvium in this wash is part of the post-basin-range sequence.

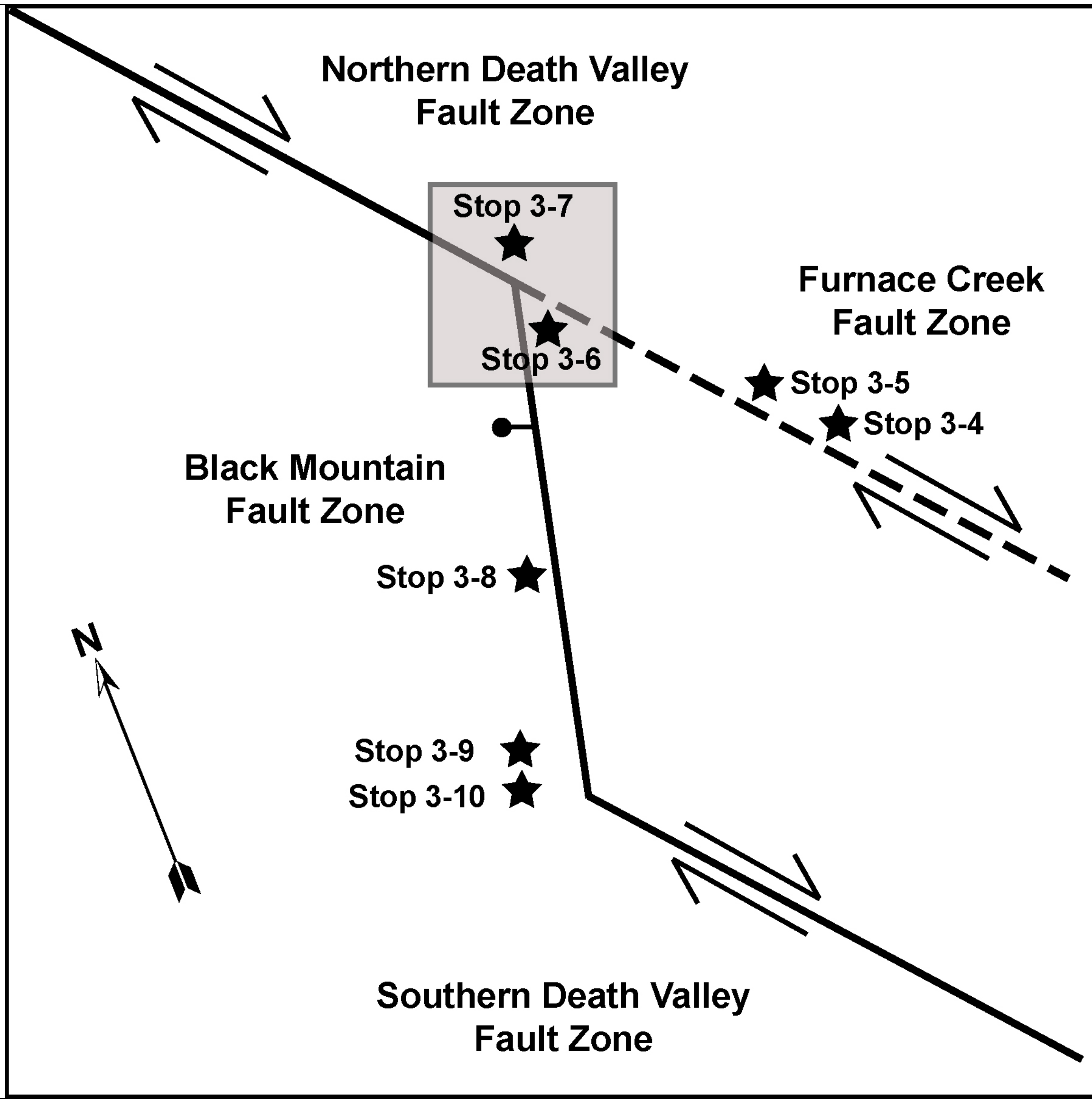

Figure 3-7. Simplified diagram showing major fault zones in the Death Valley Fault System and field trip stops. Solid lines indicate active fault zones. Dashed line indicates inactive fault zone. Black Mountain Fault Zone connects northern and southern Death Valley Fault right lateral strike-slip fault zones resulting in the Central Death Valley **Pull Apart Basin** (Stop 3-8). Modified from Machette, et al. (2001, Figure J-2).

Figure 3-8. Calcite vein showing evidence of multiple deposition of layers of calcite. Host rock is a conglomerate cemented by interstitial calcite.

Figure 3-9. Boulders from modern alluvium in Furnace Creek Wash. When such sediment is lithified, it is called a conglomerate. The reddish rocks in wash walls are conglomerate.

1.7/16.6 Stop 3-5: Travertine Point (36° 22' 31.36" N; 116° 41' 06.68" W)

Tufa (spring deposits) are visible on top of the cliff face. Calcite veins, like those seen at Stop 3-4, lead up to the paleospring deposits: the low whitish mound at the top of the cliff (Figure 3-10). The observation of paleospring deposits at that elevation indicates the water level in this area dropped hundreds of feet since the springs were active. A virtual geologic field trip of Death Valley has been prepared by the U.S. Geological Survey (2004).

1.6/18.2 Road to the left leads to Dante's View, a Death Valley overlook, and the Billie Mine, a borate mine in the Furnace Creek formation (syn-tectonic sequence) seen at 7:00.

7.2/25.4 Stop 3-6: Zabriskie Point (36° 25' 15.08" N; 116° 48' 39.94" W)

This stop is in Furnace Creek basin—an extensional feature that formed before the opening of Death Valley. The basin was about 10 km (6.2 mi) wide and extended southeast about 60 km [37.3 mi] into the southern Amargosa Desert area (Figure 3-5) (Wright, et al., 1999). The oldest rocks seen in the immediate vicinity of Zabriskie Point are the yellow and tan, thinly bedded fluvial and lacustrine sediments of the Artist Drive Formation (14–6 my) (syn-basin-range sequence). They are interpreted as representing a period fluvial deposition before maximum extension of the Furnace Creek Basin (Wright, et al., 1999). The period of maximum extension is represented by the rocks that include conglomerates, sandstones, and lacustrine carbonates of the Furnace Creek Formation (6–5 my) (syn-basin-range sequence). They show evidence of the progressive unroofing of the Black Mountains to the south (Stop 3-8). These rocks are unconformably overlain (Figure 3-11) by the Funeral Formation (5–3 my). The Funeral Formation consists of basalts and conglomerates (alluvial fans) seen along CA 190. Opening of Death Valley is thought to have started about 5 mya and is ongoing along the Black Mountain fault zone (Stop 3-8) (Marchette, et al., 2008). From the Zabriskie Point overlook looking southwest and west, one sees the Panamint Mountains on the west side of Death Valley.

The diversion of Furnace Creek at Zabriskie Point (Figure 3-12) was constructed to reduce flooding in the Furnace Creek Inn area farther downstream. Diversion of Furnace Creek has resulted in excessive erosion of the alluvium in Furnace Creek upstream and of the Furnace Creek Formation downstream and deposition in an alluvial fan at the mouth of Gower Gulch in Death Valley (Figure 3-13). The eroded material is deposited in Death Valley as an alluvial fan at the mouth of Gower Gulch. (See mileage 2.5 on second half of Day 3.)

Return to CA 190.

From this point on, there are several good examples of **angular** **unconformities** along both sides of the road (Figure 3-11).

3.4/28.8 Furnace Creek Inn.

0.2/29.0 Badwater Road to the left.

0.7/29.7 Turn right into campground. Drive to back of campground.