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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Regional Hydrology Field Trip (Charge No. 5704-131)

PLACE/DATE: Yucca Mountain Region, November 15-19, 1993

AUTHORS: Gordon W. Wittmeyer, William M. Murphy, Ron Green, Vivek Kapoor, and A. Ross Bagtzoglou

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PERSONS PRESENT:

CNWRA	NRC
W. M. Murphy	T. Nicholson
G. Wittmeyer	P. Justus
L. McKague	
A. R. Bagtzoglou	
R. Green	
V. Kapoor	
B. Sagar	

BACKGROUND AND PURPOSE:

The CNWRA has recently initiated a research project on the hydrogeology of the Death Valley Region of Nevada and California. This research has been undertaken to determine the potential for changes to the regional hydrologic regime that might adversely affect the ability of the proposed Yucca Mountain (YM) repository to safely contain spent nuclear fuel. The site, which lies in the central portion of the Death Valley Region, has been selected for the proposed mined geologic repository because of the favorable geochemical and hydrogeologic conditions provided by its 700 meter thick unsaturated zone. Siting the repository in the unsaturated zone may significantly reduce the potential for waste canister corrosion and subsequent dissolution of the waste form. Moreover, the low water flux rates that are presumed to exist in the unsaturated zone reduce the likelihood that radionuclides that are dissolved will be rapidly transported to the accessible environment. Mechanisms that may saturate the repository horizon, and thus compromise favorable conditions provided by the site, include rapid infiltration of water from the surface through highly conductive fracture networks and an increase in the elevation of the regional water table. The first mechanism is a site-scale or subregional issue and is not addressed by this research project. Elevation of the water table may occur due to increased recharge to the regional carbonate system along stream channels and mountain fronts in topographically closed basins 100 km to the north and northeast of YM. Even if elevation of the regional water table does not saturate the repository block, the reduced thickness of the unsaturated zone has the potential to significantly diminish travel times within the vadose zone. The primary purpose of this field-trip was to familiarize those working on the research project with the general physiography, geology and hydrology of the Death Valley Region with particular emphasis paid to understanding the hydrogeology of the immediate YM area.

SUMMARY OF PERTINENT POINTS:

Although more than one day of the field trip was spent examining various facilities and test sites in Area 25 specifically developed for the YM Project, most of the field trip was devoted to investigating geologic and hydrologic features which provide evidence of the nature of recharge and discharge to the regional flow system. Recharge areas examined during this trip were on the upland plateaus at NTS, Rainier Mesa, and Pahute Mesa. Discharge areas examined were at Ash Meadows, Death Valley, and Oasis Valley. In addition, paleo-discharge sites at the Horse Tooth Spring deposits and near Travertine Point in Furnace Creek Wash, Death Valley National Monument, were visited. The knowledge of the regional physiographic, topographic, geologic, and hydrologic setting gained during this field trip will prove to be invaluable in reviewing existing flow models and in developing alternative conceptual flow models of the hydrogeologic regime. The major recharge areas in the Kawich, Groom, Pahranagat, Sheep, and Spring ranges were not visited. However, recharge at Rainier Mesa and Pahute Mesa, which is readily studied within the extensive network of tunnels and boreholes constructed for weapons testing, provides some insight to the nature of recharge mechanisms occurring in the major recharge zones. Except for Franklin Lake Playa, all of the primary regional discharge areas for the Death Valley region were examined. Future field trips are planned to increase understanding of the relationship between local and regional flow systems.

SUMMARY OF ACTIVITIES:

1. DAY ONE.

1.1 Following their arrival in Las Vegas, G. Wittmeyer and W. Murphy rented two vehicles, and met P. Justus at the NRC site office who supplied detailed itineraries for excursions on the Nevada Test Site (NTS) and some field equipment. The NRC site office staff provided excellent support in arranging access and guiding field observations on the NTS.

1.2 B. Sagar, L. McKague, R. Bagtzoglou and V. Kapoor of the CNWRA and T. Nicholson of NRC arrived and the assembled group proceeded south from Las Vegas on I-15. The rest of the first day of the field trip basically followed that outlined in Attachment 1 to which the reader is referred for more in-depth description of the geology along the route. The group took exit 33 heading west on state route 160 approximately 3.6 miles south of the junction of Tropicana Blvd. and I-15. State route 160 heads west-northwest to Pahrump via Spring Mountain Pass.

1.3 The group took route 372 west out of Pahrump and stopped at its intersection with a dirt road leading north into Stewart Valley. L. McKague gave an overview of the geology of the Resting Spring Range to the west and the Nopah Range to the southwest. (see Attachment 1)

1.4 The group drove north through Stewart Valley. Entries for Day One mileposts 62.4 through 75.0 in Attachment 1 provide details of the geology in Stewart Valley. (Location indicated on Attachment 2, stop 1.4)

1.5 The group entered the Ash Meadows area at approximately 4:15 pm. Discharge along the Ash Meadows spring line is believed to be conveyed from the Paleozoic carbonate aquifer to the surface along a buried fault. Total spring discharge at Ash Meadows exceeds 0.63 cubic meters per second, 72 percent of which is derived from Crystal Pool, Fairbanks Spring, Big Spring, Longstreet Spring, and Rogers Spring which discharge through the valley fill aquifer (Winograd and Thordarson, 1975). Water discharging in the Ash Meadows area is believed to be recharged from the Pahranagat, Sheep and Spring ranges. Geochemical and potentiometric data suggest that water in the carbonate aquifer under Frenchman Flat and Yucca Flat mixes with some leakage from overlying tuffaceous rocks and discharges at Ash Meadows. Point of Rocks Spring and Devils Hole, which discharge directly from the lower carbonate aquifer, were inspected during the field trip. L. McKague described sample collection of calcite core from the wall of Devils Hole below the water table. The calcite cores were studied by Winograd et al. (1992). Through uranium series dating and oxygen isotope analysis, this material provides a continuous climatic record for the period from about 600,000 to 50,000 years before present. An implication of the detail preserved in the record is that groundwater travel times to the discharge point are short (e.g., significantly less than 5000 years). Several other springs in the Ash Meadows area were observed, and work by Winograd and Pearson (1977) was discussed. They concluded that the anomalous ^{14}C content of the water in Crystal Pool (in Ash Meadows) indicates mega-scale (e.g., tens of kilometers) channeling, rapid flow in the channel, and focused discharge at Crystal Pool. (Location indicated on Attachment 2, stop 1.5)

1.6 The group departed Devils hole at dusk and headed north-northeast past the Amargosa Clay deposits. A detailed description of the distribution of clay facies is given in Attachment 1 under Day One, mile 87.6. As described in Attachment 1, the "distribution, mineralogy, and geochemistry of theses clay deposits suggest that in the Pliocene springs were more widespread and had greater discharge." The clay minerals that developed from the alteration of volcanic glass were controlled by the chemistry of the water.

2. DAY TWO.

2.1 CNWRA and NRC field trip participants arrived at Mercury at 7:00 am to obtain badges and meet their Q-cleared escorts, Chuck Russell (DRI), James D. Donithan (DRI), Phil Justus (NRC), and Randy Leonard (DOE). The assembled group drove north on Mercury highway past Frenchman Flat, and through Yucca Flat to the Rainier Mesa tunnel complex. At the building complex outside the entrance to P-tunnel Barbara Harris-West of the Defense Nuclear Agency (DNA) met the group, delivered a briefing on the use of miner self-rescue devices, and outfitted all participants with hard hats, steel-toed boots and flashlights. In addition, Barbara Harris-West gave a brief description of the tuff units penetrated by the Rainier Mesa tunnel complex. Both P-Tunnel and N-Tunnel portals are in the Tunnel Beds, which are partially zeolitized bedded tuffaceous units stratigraphically below the Paintbrush Tuff. P-Tunnel is "dry" whereas much water is observed in N-tunnel. A postulated rationale for the difference is that P-Tunnel intersects the axis of the depositional low called the Aqueduct Syncline. It has been postulated that water flowing down the limbs of the syncline is focused at the fold axis and becomes perched. This flow has resulted in the alteration of the zeolites to clay minerals along the axis of the syncline. (Location indicated on Attachment 3, stop 2.1)

2.2 Following a short drive from P-tunnel to N-tunnel, the tour participants escorted by B. Harris-West entered N-tunnel via railcar. Rainier Mesa and Pahute Mesa are remnants of an eroded volcanic plateau that range in altitude from 1800 to 2300 meters and receive over 32 cm/yr of precipitation (Jacobson et al., 1986). Rainier Mesa is composed of a series of welded, zeolitized and friable tuffs of Miocene age that dip 10 to 25 degrees to the west and south (Russell et al., 1987). Water that infiltrates Rainier Mesa is presumed to travel through networks of fractures within the tuff units until it reaches the regional water table located in the Paleozoic carbonate aquifer 1070 meters below the mesa (Jacobson et al., 1986). An extensive network of tunnels for underground nuclear testing has been constructed in the southeast side of Rainier Mesa at depths ranging from 240 to 700 meters below the surface. Water encountered during mining of the tunnels is derived from perched water zones that develop where the fractures in the tuffaceous materials are poorly connected. When perched water zones are first encountered flow rates into the tunnels may be quite great but usually decrease rapidly with time suggesting that flow is initially derived directly from storage. Participants of the field trip were escorted by representatives of the DNA into a section of N-tunnel in Rainier Mesa which intersects a fault zone discharging water at a rate of 4 to 10 liters per minute. Based on comparison of the δD and $\delta^{18}O$ composition of N-tunnel water with local precipitation Russell et al. (1987) infer that the perched water body is of meteoric origin and receives recharge primarily during winter. According to Russell et al. (1987) "the ground-water regime in Rainier Mesa is characterized by rapid fracture flow in the upper welded formations, slower interstitial flow through the [underlying] friable tuffs ... and slow fracture flow through the aquitard created by the highly zeolitized [tuffs]." White et al. (1980) have shown that fracture water and interstitial (pore) water in Rainier Mesa have different chemistries indicating separate although related origins. (Location indicated on Attachment 3, stop 2.2)

2.3 After departing N-tunnel the tour participants drove to the ER-12-1 drill pad for lunch. Drillhole ER-12-1 was drilled to gather information for the groundwater characterization portion of the NTS environmental restoration project. L. McKague gave a briefing on the geologic units penetrated by the drillhole and the implications for the transport of tritiated water from Rainier Mesa complex to the Yucca Flat groundwater system. Due to thrust faulting, it was anticipated that the borehole would intersect the older Devonian Simpson dolomite before penetrating the Mississippian Eleana formation. However, the ER-12-1 logs indicated that thrust faulting had twice placed Simpson dolomite on top of Eleana formation. The borehole appears to have bottomed in an altered igneous rock. (Location indicated on Attachment 3, stop 2.3)

2.4 The tour participants departed the ER-12-1 drill pad and drove to Pahute Mesa via Stockade Wash road heading north at its intersection with Pahute Mesa road. The group stopped at a road cut at the rim of Pahute Mesa where L. McKague gave a briefing on the calderas, located to the south-southwest, and on the bedded non-welded and welded tuffs exposed in the road cut. At this stop the Rainier Mesa Tuff flowed to the northwest in a pre-existing channel cut into the pre-Rainier Mesa Tuffs. (Location indicated on Attachment 3, stop 2.4)

2.5 The group then proceeded north onto Pahute Mesa and toward Dead Horse Flat. Pahute Mesa constitutes the primary watershed for Fortymile Canyon Wash, Stockade Wash and the Amargosa River, and lies to the north and northwest of Rainier Mesa. Oxygen and hydrogen isotope data indicate that groundwater underneath Pahute Mesa flows toward Oasis Valley rather toward Yucca Mountain and Fortymile Canyon (White and Chuma, 1985). As part of the environmental restoration program conducted at NTS, the Desert Research Institute (DRI) has developed an experimental recharge facility at Dead Horse Flat in the north central portion of Pahute Mesa. Field trip participants were given a briefing on the automated meteorologic station and soil moisture measuring equipment installed to correlate precipitation events with deep infiltration. Soil moisture measuring equipment consist of a vertical array of horizontally emplaced time-domain reflectrometry probes installed at depths of approximately 0.9 m. (Location indicated on Attachment 3, stop 2.5)

2.6 The group left Dead Horse Flat and drove south and east on Pahute Mesa road to the intersection with Tippipah Highway where they turned south toward Yucca Lake. In Yucca Flat the group stopped at borehole ER-6-3 which was drilled as part of the NTS environmental restoration program to determine the groundwater outflow from southern Yucca Flat. C. Russell of DRI gave a briefing on the hydrostratigraphy of Yucca Flat. (Location indicated on Attachment 3, stop 2.6)

2.7 The group left ER-6-3 and drove south on the Mercury Highway toward Frenchman Lake to visit the Cambric radionuclide migration experiment field site. This experiment was initiated in 1974 to study rates of the underground migration of radionuclides from explosion-modified zones at Nevada Test Site (NTS). As the Cambric detonation point is only 294 m below ground surface, the re-entry drilling and sampling operations were less expensive than for more deeply buried sites. Samples of water and soil were taken to determine the radionuclide distribution between the solid material and water. Beginning in October 1975, water was pumped (at the rate of 600 gal/min) from a well 91 m from the Cambric cavity to study radionuclide transport under field conditions. In 1978 tritium was detected in the weekly analyzed samples. Tritium concentrations peaked in 1980. A better understanding of the groundwater transport of radionuclides from nuclear explosion cavities was developed by this experiment. The Cambric migration studies are summarized in Bryant (1992). The group then returned to Beatty via Mercury. (Location indicated on Attachment 3, stop 2.1)

3. DAY THREE

3.1 The group left Beatty and drove to the Lathrop Wells gate and into area 25 of the NTS. The group then proceeded to the Hydrologic Research Facility (HRF) located in Jackass Flats. The facility has been designed to evaluate aspects of the hydrology of the Yucca Mountain Project. The facility is operated by the USGS and their consultants. Both the surface and subsurface hydrology of Yucca Mountain are investigated in tasks conducted at the HRF.

Surface hydrology investigations include the monitoring of the climatological conditions of the site. Climatological stations established at Yucca Mountain provide data to characterize weather events (in terms of spatial extent, frequency, duration, intensity, etc.). Video tapes of weather events at the site provide additional evidence to character the climate. This information is to be used to evaluate the past, present and future climate of the site.

The hydraulic properties of the geologic units at Yucca Mountain are measured at the HRF including saturated hydraulic conductivity, porosity, bulk and grain density, the moisture retention curve and diffusivity of these media. Multiple techniques are used to measure some of these characteristics. For example, the moisture retention curve is measured with several different pressure plate extractors and a water activity meter. Diffusivity is measured in different experiments, some of which (those to be performed in a constant climate chamber) were not yet operational at the time of this visit.

The hydraulic properties of other media, in addition to those representing the straight stratigraphic column at Yucca Mountain, are being evaluated. Fracture infill material from prominent fractures or faults are also undergoing the hydraulic tests listed above. In addition, Calico Hills samples collected from locations that were altered by past hydrothermal activities, are being evaluated to assess changes in hydraulic properties due to hydrothermal alteration. (Location indicated on Attachment 3, stop 3.1)

3.2 A bulldozer cut along the south side of Antler Ridge has exposed a large extent of the Ghost Dance Fault. The cut was perpendicular to the strike of the fault. After most surficial material was removed by the bulldozer, a combination of compressed air and water was used to wash away remaining dirt and debris. The resulting cut exposed the fault and provided access for inspecting the subsurface. The cut extended for more than 700 feet. The width of the fault is approximately 700 feet.

The Ghost Dance Fault is evidenced as a brecciated or rubble zone. Individual fractures in the fault zone have exposed apertures of up to several centimeters. Most larger fractures are filled with carbonate or silica minerals. Because of activities by the bulldozer and surface erosion, it is difficult to ascertain the extent of open fractures, however, there is evidence at the cut that numerous open channels penetrate the fault zone.

It was not certain at the time of the trip whether the cut has exposed the full extent of the Ghost Dance Fault. (Location indicated on Attachment 3, stop 3.2)

3.3 The next stop was at the crest of Yucca Mountain. John Stuckless of the USGS provided an impromptu discussion of the physiographic and geologic setting of Yucca Mountain. Prominent geologic features viewed from Yucca Crest include Solitario Canyon, the cinder cones in Crater Flat, Bare Mountain on the west side of Crater Flat, the Amargosa Desert to the west-southwest, the Funeral Mountains which form the eastern boundary of Death Valley and Mount Charleston, the highest peak in the Spring Mountains directly to the south. (Location indicated on Attachment 3, stop 3.3)

3.4 At Trench 14 and 14A. L. McKague, W. Murphy and P. Justus described activities associated with the trenches. Trench 14 was initially excavated to explore the northern extension of the Bow Ridge Fault. A second deepening of the trench exposed a wide zone of brecciated rock cemented with silica and calcite. Several generations of carbonate veins with cross-cutting relations are apparent. These deposits have stimulated considerable controversy, particularly because of arguments by J. Szymanski, formerly of the DOE, that they are a consequence of discharge of hydrothermal solutions associated with episodic periods of high heat flow and seismic pumping. In contrast, most DOE researchers attribute the vein filling to infiltration of surface water (runoff from Exile Hill) along a zone of preexisting brecciation. This controversy has stimulated further exploration and deepening of the trenches. The breccia zone in Trench 14 clearly tends to pinch out with depth. Among the strongest data in support of the supergene/pedogenic origin of the deposits (as opposed to the hypogene/hydrothermal origin) is that the isotopic character of the deposits resembles closely soil zone materials and materials significantly above the water table in Yucca Mountain. The calcite-silica deposits tend to differ significantly in isotopic composition from authigenic materials from below the water table (e.g., Stuckless et al., 1992). A short walk up Exile Hill from Trench 14 provided field trip participants with a close overview of the construction area for the ESF portal. (Location indicated on Attachment 3, stop 3.4)

3.5 The group left Trench 14 and made the short drive to the ESF staging area. After preliminary discussions on difficulties encountered when starting the shaft in brecciated rock, the group was allowed to enter the ESF starter tunnel and the experimental alcove. Excavation of the alcove was ongoing at the time of the visit. This portion of the shaft and alcove were constructed using drill and blast techniques. The tunnel boring machine which will be used to bore the main ESF adit will be delivered in the Spring of 1994, with actual excavation scheduled to begin by August, 1994.

Most of the starter tunnel wall cannot be inspected because the surface has been covered with metal mesh held in place by rock bolts and covered with concrete. Only those portions of the shaft that are under construction have exposed walls. Based on discussions with on-site personnel, it appears that this practice will continue as the tunnel construction advances. Access to the interior of the rock will only be gained through the placement of testing boreholes. Instruments to measure in situ rock stresses and other media properties and conditions have been installed in the boreholes already constructed.

The exposed shaft wall was inspected in the alcove, where the surface has not yet been covered with mesh and concrete. Many fractures are exposed in the wall of the experimental alcove, some of which were filled with grout injected into the rock bolt holes in the main drift. Rock bolt grout apparently extends several meters around the 10 ft. long bolts. A discussion ensued concerning whether or not extensive grouting and shotcrete sealing of the walls, particularly in fractured areas, would preclude observation of episodic fracture flow in the ESF. (Location indicated on Attachment 3, stop 3.5)

3.6 The site of the Large Block Test (LBT) at Fran Ridge was visited next. Jim Blink, the on-site representative for LLNL, was present for a presentation and discussions on the LBT. The block is designed to have surface dimensions of 3 by 3 meters and a height of 4 meters. The block will be left attached to the bedrock at its base.

The surface of the block had been exposed and the tentative location has been designated by the placement of a metal template to be used to guide the drilling of vertical boreholes into the block. After the boreholes have been installed, rock will be removed from around the block through a series of lifts. Immediately after rock removal, a large loading frame will be installed to maintain compressive loading on the vertical walls of the block. Rock will be removed through several lifts until the rock surrounding the entire 4 m height of the block has been excavated.

J. Blink indicated that the block will be subjected to a compressive load similar in magnitude to that expected at the repository depth. A series of five cylindrical heaters are to be horizontally placed 1.5 m from the base of the block. There are to be no external guard heaters nor is the block to be insulated. A detailed work plan for the LBT is not yet available. (Location indicated on Attachment 3, stop 3.6)

3.7 The group departed Fran Ridge, returned badges at Lathrop Wells gate and headed west on US highway 95 toward Beatty. The group stopped at the Horse Tooth spring deposits located south of Crater Flat approximately five km east of the intersection of Steve's Pass road and US highway 95 at an approximate elevation of 800 meters. According to Paces et al. (1993) these deposits are composed of "[w]ell-cemented, fine-grained nodular carbonate with, porous vuggy structure," and "[contain] only a small ... amount of fine-grained, well-sorted detritus." A uranium series disequilibrium date from the Horse Tooth Deposit yields 45.7±4.9 ka. (Paces et al., 1993). Dates obtained from these spring deposits as well as from those to the north in Crater

Flat imply that there have been repeated fluctuations in the water table of up to 116 m above present levels. (Location indicated on Attachment 2, stop 3.7)

3.8 The group departed the Horse Tooth Deposit and headed west on US highway 95 to Beatty. The group passed through Beatty at dusk and continued north to Oasis Valley road. According to Winograd and Thordarson (1975) groundwater from Pahute Mesa and Timber Mountain predominantly moves southwestward through Tertiary tuff units to discharge areas in Oasis Valley. Waddell et al. (1984) state that spring discharge at Oasis Valley is controlled by the presence of low-permeability rocks downgradient from Beatty. Although total spring discharge throughout Oasis Valley is only estimated to be 0.078 cubic meters per second (Malmberg and Eakin, 1962), field trip participants were readily able to identify discharge areas by the presence of phreatophytes. (Location indicated on Attachment 2, stop 3.8)

4. DAY FOUR

4.1 The group left Beatty and headed east on US highway 95 to the intersection with the road over Steve's Pass at milepost 46.3. The group drove north-northeast into Crater Flat to Red Cone which is some 1.2 ma old. Red Cone represents a paleo-discharge area for juvenile water. To the north-northeast lies Black Cone, which is of similar age, and to the south-southwest lies Little Cone also of similar age. At the summit of Red Cone L. McKague gave a brief overview of the complex folded and faulted Paleozoic strata exposed in Bare Mountain directly to the west. (Location indicated on Attachment 2, stop 4.1)

4.2 After leaving Red Cone the group continued driving east-northeast and entered Solitario Canyon which bounds the western flank of Yucca Mountain and provides an excellent overview of the Tiva Canyon member of the Paintbrush tuff and underlying units. L. McKague pointed out numerous hillslope boulder deposits on the western flank whose presence has been used by DOE to indicate the absence of extreme erosion at Yucca Mountain. The stability of these hillslope boulder deposits is based largely on dating of the desert varnish on the boulders. While heading out of Solitario Canyon the group stopped at the drill pad for DOE borehole WT-7 located at the south end of Boomerang Ridge. Several excellent rock samples were taken from the outcrop of densely welded Tiva Canyon Tuff exposed at the west edge of the drill pad. Most of the rock in this area is highly brecciated with secondary vein mineralization consisting primarily of carbonate with some silica. (Location indicated on Attachment 2, stop 4.2)

4.3 The group then returned to US highway 95 via Steve's Pass road and headed east to Lathrop Wells and the intersection with state route 29. The group then headed south on state route 29 to Death Valley Junction, crossing the dry bed of the Amargosa River just north of the Nevada-California state line. From Death Valley junction the group headed due west on California route 190. Located just east of the monument boundary is an easily accessible set of vertical fracture zones several meters in length, filled with travertine composed of calcite with thin bands of hematite, is located within fifty meters of the road. Presence of these deposits indicates that either water levels within the carbonate units in the Funeral Mountains were much higher in the past or that there has been substantial uplift of the Funeral Mountains. Travertine Point is located approximately 25 km west of Death Valley Junction in the valley between the Funeral Mountains to the north and the Greenwater Range to the south along the westward reach of Furnace Creek Wash. Approximately 1.5 km west of the first stop and several hundred meters above the road, on the north wall of the canyon, there are vertical fracture zones hundreds of meters in length which have been infilled with calcite believed to be derived from upwelling waters from the carbonate units in the Funeral Mountains. (Location indicated on Attachment 2, stop 4.3)

4.4 Continuing west on 190 the next stop was Zabriskie Point. Zabriskie Point is located on extensively eroded badlands composed of very friable playa deposits of the Pliocene Furnace Creek Formation. In 1941 a diversion dam was constructed to divert the flow of Furnace Creek Wash into the much smaller drainage of Gower Gulch. This has resulted in extensive headward erosion accompanying increased fan building at the mouth of Gower Gulch. The vista at Zabriskie Point includes Telescope Peak to the southwest, at 3368 m it is the highest point in the Panamint Range. (Location indicated on Attachment 2, stop 4.4)

4.5 The group proceeded to the Death Valley National Monument headquarters at Furnace Creek Ranch and stopped for lunch. Waddell et al. (1984) suggest that Franklin Lake Playa (Alkali Flat) and Death Valley are the primary discharge points for the Alkali Flat-Furnace Creek Ranch subbasin. Water discharges near Furnace Creek Ranch in Death Valley through springs located several hundred meters above the valley floor (Waddell et al., 1984). The major springs in the Furnace Creek area, Travertine Spring, Texas Spring and Nevares Spring, discharge approximately 0.16 cubic meters per second from the lower carbonate aquifer through overlying Quaternary gravel deposits. This discharge is sufficient to supply irrigation water to orchards of date palms at Furnace Creek. Following lunch the group headed south from Furnace Creek Ranch on state route 178 stopping just south of the intersection of routes 178 and 190 to inspect a fault scarp on the east side of the road with approximately 2 m of vertical displacement. L. McKague delivered a briefing on strike-slip faulting in the Death Valley area and the origin of the Death Valley trough by pull-apart action along the Death Valley - Furnace Creek fault zone. (Location indicated on Attachment 2, stop 4.5)

4.6 L. McKague, B. Sagar and R. Green returned to Las Vegas via Death Valley Junction while those continuing on the field trip proceeded south on route 178 stopping at Devil's Golf Course and Badwater. Devil's Golf Course lies in the central part of the salt pan on the valley floor. The deposits at Devil's Golf Course are composed of very rough, silty rock salt. Badwater is the lowest point in the continental US at -282 m.

4.7 Continuing south on route 178 the group stopped to observe ancient strand lines incised on Shoreline Butte which are postulated to have been made by wave action from lake Manly. For the return trip to Las Vegas, route 178 was taken east through Jubilee Pass and Greenwater Valley to route 127 south to Shoshone, California. From Shoshone route 178 was taken east through the north end of Chicago Valley to Pahrump, and from Pahrump route 160 was taken to Las Vegas via Spring Mountain Pass.

IMPRESSIONS/CONCLUSIONS:

The field proved to be beneficial for all participants, even for those not directly involved in the regional hydrogeology research project. All participants were extremely impressed by the scope and quality of the experimental work being conducted at the HRF by Alan Flint and his coworkers. The Rainier Mesa tunnel complex is clearly an excellent analog for the hydrogeologic regime which might evolve at Yucca Mountain under conditions of increased precipitation and infiltration. It is unfortunate that the DNA will permanently close the tunnel complex this spring. The utility of using radiometric dates obtained from fossil spring deposits to bound the height of past water elevations and/or rates of tectonic uplift is recognized by DOE. Information gained from dating of the Crater Flat and Horse Tooth fossil spring deposits may provide the most convincing evidence that although the water table has been considerably higher in the past, it has never risen high enough to saturate the repository horizon. The most disturbing bit of information gathered during the field trip was the revelation that current YMP plans call for the entire ESF to be lined with shotcrete once the fractures and faults have been mapped. As noted above in the summary of activities, complete shotcreting will preclude observation of potential episodic flow of water through permeable fracture zones intersected by the ESF.

PENDING ACTION: None

RECOMMENDATIONS: None.

PROBLEMS ENCOUNTERED: None.

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ATTACHMENTS: (Attachments available from G. Wittmeyer upon request)

1. Field Trip Guidebook T186.
2. Map of Nevada Test Site.
3. Death Valley, California; Nevada Map NJ 11-11.

SIGNATURES:

Gordon W. Wittmeyer — 3/16/94
Date

William M. Murphy — 3/16/94
Date

Ronald T. Green — 3/16/94
Date

Vivek Kapoor — 3-16-94
Date

Amvrossios Bagtzoglou — 3/16/94
Date

CONCURRENCE SIGNATURES:

R. G. Baca
Manager, Performance Assessment — 3/22/94
Date

H. L. McKague
Manager, Geologic Setting — 3/22/94
Date

Budhi Sagar
Technical Director — 3/23/94
Date

March 16, 1994
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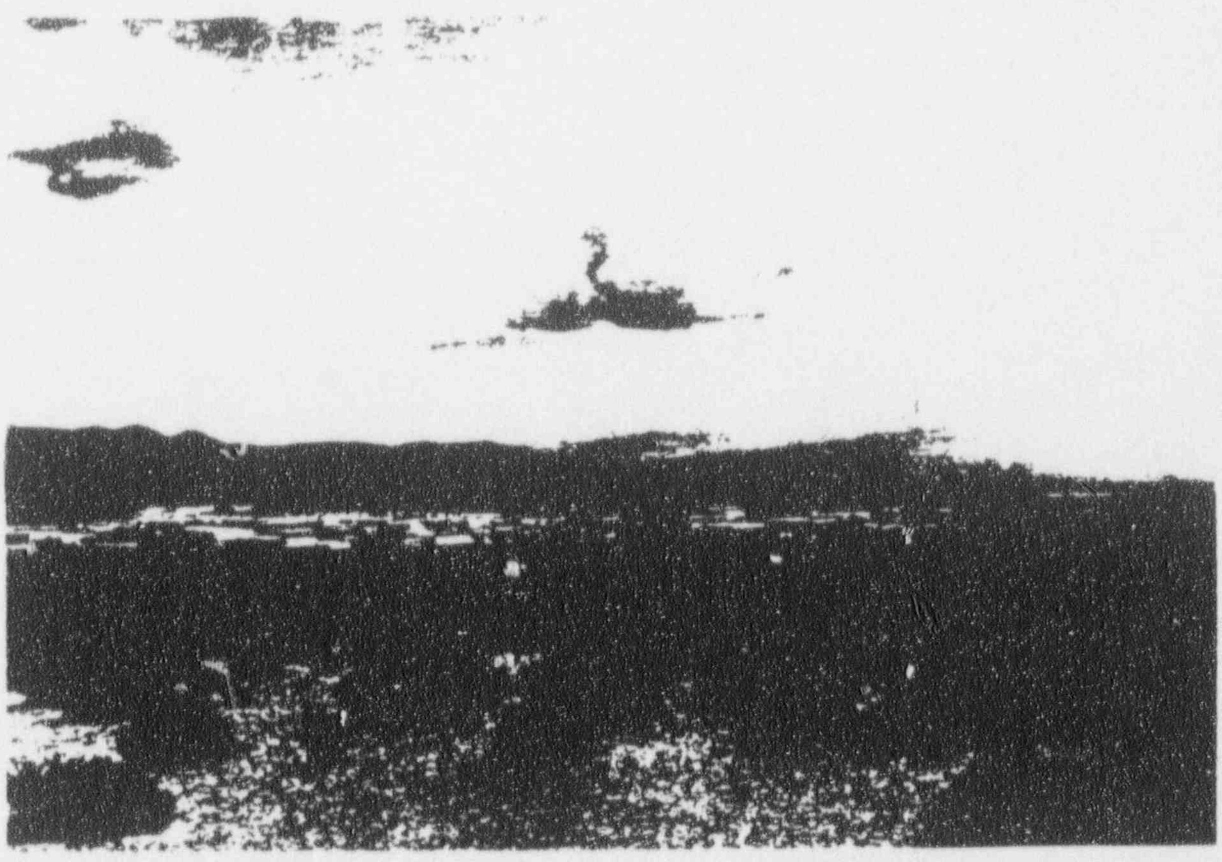
ATTACHMENT 1

28th International Geological Congress

The Geology of the Nevada Test Site and Surrounding Area

Field Trip Guidebook T186

Leaders:
H. Lawrence McKague, Paul P. Orkild
and Steven R. Mattson



Clark and Nye Counties, Nevada
July 5–7, 1989

The Geology of the Nevada Test Site and Surrounding Area

Clark and Nye Counties, Nevada
July 5–7, 1989

Field Trip Guidebook T186

Leaders:
H. Lawrence McKague *Paul P. Orkild* *Steven R. Mattson*

Contributions By:
F. M. Byers *Bruce M. Crowe* *E. D. Davidson*
Holly A. Dockery *Terry A. Grant* *E. L. Hardin*
Robert A. Levich *A. C. Matthusen* *Robert C. Murray*
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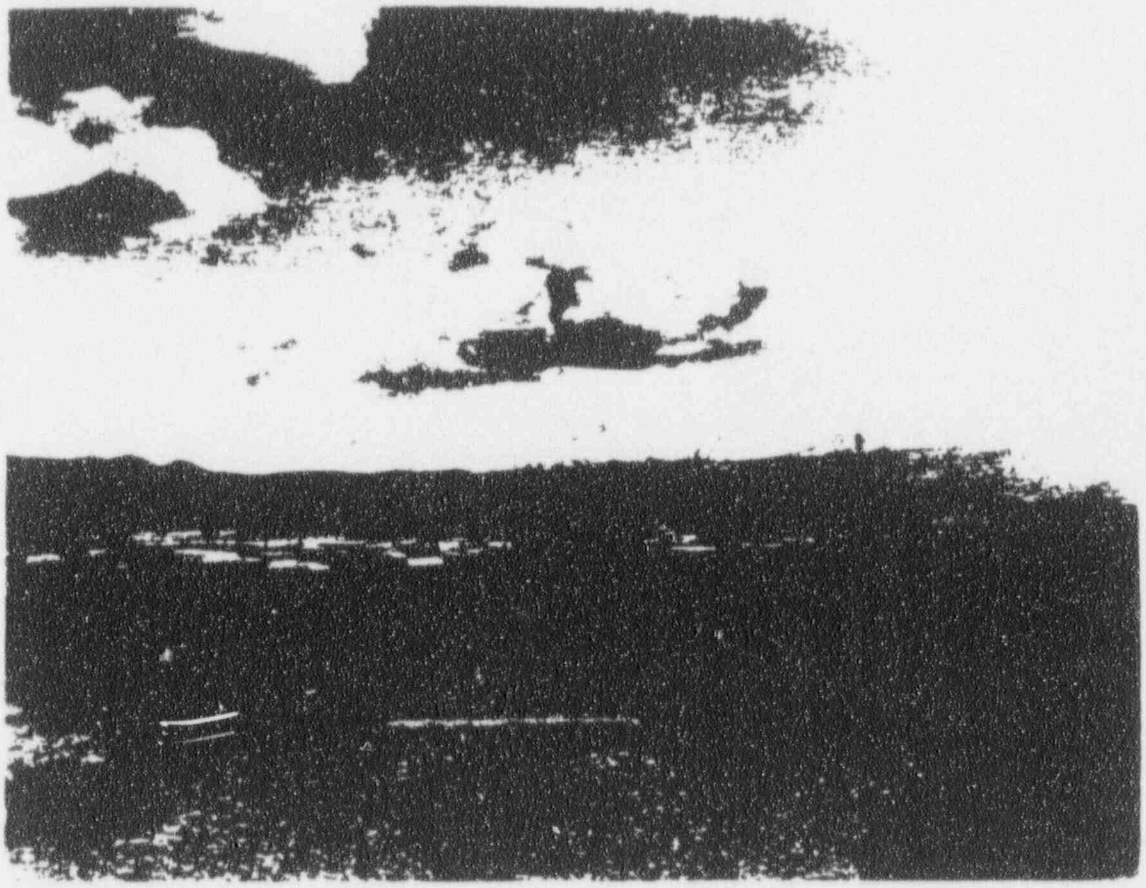
American Geophysical Union, Washington, D.C.



COVER A view southeast across Mercury, NV towards the snow covered Spring Mountains. Mt. Charleston is the high peak in the Spring Mountains near the left edge of the photograph. The bare ridge just beyond Mercury is the southwestern extension of the Spotted Range. Mercury Valley is the northwest extension of the Las Vegas shear zone.

The Geology of the Nevada Test Site and Surrounding Area

IGC FIELD TRIP T186
THE GEOLOGY OF THE NEVADA TEST SITE AND SURROUNDING AREA:
A FIELD TRIP FOR THE 28th INTERNATIONAL GEOLOGICAL CONGRESS

H. Lawrence McKague(1), Paul P. Orkild(2), Steven R. Mattson(3)

With Contributions by

F. M. Byers(4), Bruce M. Crowe(4), E. D. Davidson(3), Holly A. Dockery (1), Terry A. Grant(3), E. L. Hardin(3), Robert A. Levich(5), A. C. Matthusen(3), Robert C. Murray(3), H. A. Perry(3), and Donna Sinks(3)

INTRODUCTION

The Nevada Test Site (NTS) was established on December 18, 1950, to provide an area for continental testing of nuclear devices. In January of 1951, testing began with an airdrop into Frenchman Flat in conjunction with Operation Ranger. In addition to airdrops, above ground testing included surface detonations, tower shots, and balloon suspensions. Underground testing began in 1957, and since 1963, all events have been buried in large-diameter drill holes or tunnels. Geologists from the U.S. Geological Survey (USGS) mapped much of the NTS region between 1960 and 1965. These maps formed the basis for subsequent studies by Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Sandia National Laboratories, and the USGS. A good understanding of the stratigraphy, structure, geochemistry, and physical properties of the rocks is essential for containment of underground nuclear tests. Many of the recent geologic studies at NTS, particularly in Yucca Flat, Pahute Mesa, and Mid Valley, are aimed at understanding subsurface geology to help ensure complete containment. The potential nuclear waste site at Yucca Mountain is located approximately 100 miles (160 km) by road northwest of Las Vegas, Nevada, and situated on land controlled by three Federal agencies; the Bureau of Land Management, the Department of Energy (Nevada Test Site), and the U.S. Air Force (Nellis Air Force Range).

(1)Lawrence Livermore National Laboratory, Livermore, CA
(2)U.S. Geological Survey, Denver, CO
(3)Science Applications International Corp., Las Vegas, NV
(4)Los Alamos National Laboratory, Los Alamos, NM
(5)Department of Energy, Las Vegas, NV

By 1978 approximately thirty sites had been identified as potential localities for a mined underground nuclear waste repository. Work on the Yucca Mountain site began in this year. In 1982 the Nuclear Waste Policy Act was passed by Congress and in February 1983 the U.S. Department of Energy narrowed the field of possible sites to be characterized down to nine sites. In 1984 through consideration of the Draft Environmental Assessment for each site the field was reduced to five sites. In May of 1986 the environmental assessments were published for each of these sites and based upon this information three sites were chosen for continued investigation. These three sites included Yucca Mountain, Nevada (silicic ash flow tuff); Hanford, Washington (basaltic lava flows); and Deaf Smith County, Texas (bedded salt). By an amendment to the Nuclear Waste Policy Act, Congress decided, in late 1987, to characterize only one site: Yucca Mountain, Nevada. The project was formerly known as Nevada Nuclear Waste Storage Investigations (NNWSI) Project and is now known as the Yucca Mountain Project (YMP). Since 1978, the massive ash-flow tuff beds under Yucca Mountain have been intensively studied to determine their suitability as a radioactive waste repository.

FIGURE 1 is a regional map that shows the field trip route and many of the geologic features of southwestern Nevada. The older rock sequence at NTS is composed of upper Precambrian and Paleozoic rocks which were complexly deformed by Mesozoic compressional tectonism. Table I is a generalized pre-Cenozoic stratigraphic column for the area covered by this field trip. The stratigraphy can most easily be thought of as an alternating sequence of carbonate and clastic rocks (Table I, right hand column). The carbonate sequences act as aquifers. The clastic sequences usually

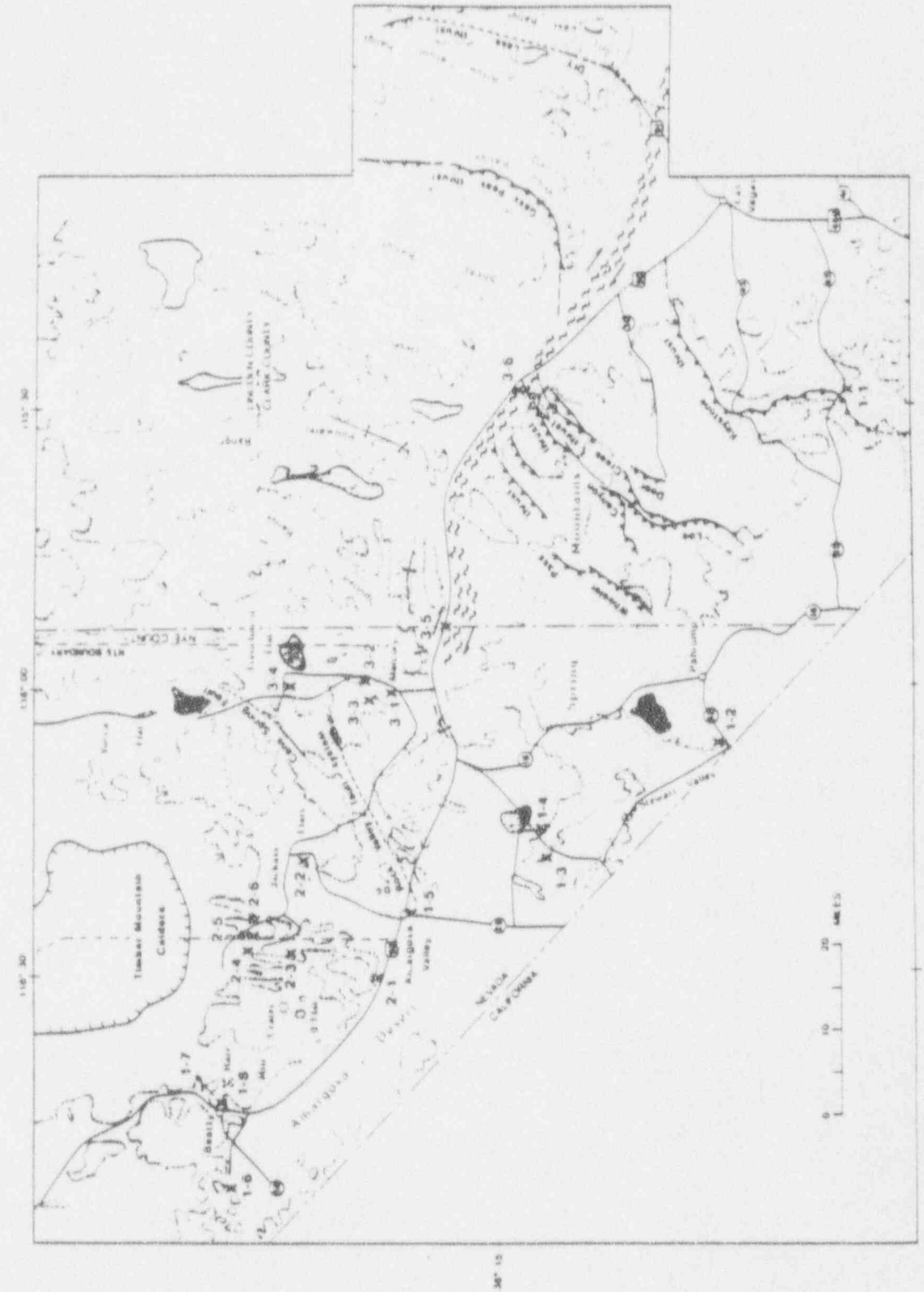


FIGURE 1. Map of southwestern Nevada showing major geologic structures, physiography and field trip stops.

TABLE I

Pre-Cenozoic Rocks Exposed in Southwestern Nevada
(modified from Orkild, 1982)

Age	Unit	Approx. Thickness (m)	Lithology	Informal Hydrologic Designation
Cretaceous	Granodiorite of Climax	___	granodiorite of Climax	
Jurassic and	Aztec Sandstone	___	sandstone	
Triassic	Chinle Formation	___	shale	
	Moenkopi Formation	___	limestone	
Permian	Kaibab Limestone	___	limestone	
	Redbeds	___	shale	
Permian and Pennsylvanian	Tippipah Limestone/ Bird Spring Formation	1100	limestone	Upper carbonate aquifer
		___		
Mississippian and Devonian	Eleana Formation (Monte Cristo Limestone)	2320	argillite quartzite limestone	Upper clastic aquitard
		___		
Devonian	Devils Gate Limestone	420	limestone	
	Nevada Formation	465	dolomite	
	(Sultan Limestone)	___	limestone	
Devonian and Silurian	Dolomite of Spotted Range	430	dolomite	
Ordovician	Ely Springs Dolomite	93	dolomite	Lower carbonate-aquifer
	Eureka Quartzite	104	quartzite	
	Pogonop Group			
	Antelope Valley Limestone	466	limestone	
	Ninemile Formation	102	siststone	
	Goodwin Limestone	290	limestone	
Cambrian	Nopah Formation	565	limestone, dolomite	
	Dunderberg Shale Member	49	shale	
	Bonanza King Formation	1400	limestone, dolomite	
	Carrara Formation	305	limestone	
		305	siltstone	
	Zabriskie Quartzite	67	quartzite	
	Wood Canyon Formation	695	quartzite, siltstone	Lower clastic aquitard
	Stirling Quartzite	915	quartzite	
Cambrian and Late Proterozoic	Johnnie Formation (base not exposed)	915	quartzite, limestone, dolomite	
TOTAL THICKNESS		11,000+		

act as aquitards. Tertiary volcanic rocks and Tertiary and Quaternary alluvium (Table II) overlie the older rocks and were deposited concurrent with Cenozoic extensional faulting. The upper Miocene ash-flow tuffs and lavas found in this area issued primarily from the Timber Mountain caldera complex located in the western part of NTS (FIGURE 1). Studies performed in conjunction with nuclear testing and radioactive waste isolation have addressed many aspects of the geologic history of NTS, which have in turn greatly enhanced our understanding of the geology of the southern Great Basin.

This guidebook has had a number of predessors. In the 1960s and 1970s the U.S. Geological Survey prepared several informal guidebooks. Some of the material in this guidebook can be traced back to these informal reports. The guidebook prepared by Dockery et al. (1985) was used extensively for the geologic descriptions along U.S. 95, and at stops 1-5, 2-1, 3-2 and 3-4. This guidebook is easier to use when traveling west from Las Vegas on US 95.

ROAD LOG

First Day Las Vegas, NV to Beatty, NV

Mileage (cumulative)

0.0 Mileage starts on I-15 and at the Tropicana Avenue on ramp. Proceed toward south on I-15. From 1:00-4:00 the Spring Mountains are a northwest-trending range of predominantly Paleozoic rocks. The transition from Paleozoic craton to miogeosynclinal facies occurs from east to west across the mountains. To the east and south of here the uppermost Precambrian and Paleozoic miogeosynclinal deposits are drastically thinner, while to the west and north they thicken. The McCullough Range is to the southeast (10:00-11:00). The northern part of this range is dominated by a 12 to 15 Ma andesitic stratovolcano. To the south the volcanic section lies unconformably on the Precambrian basement (Smith et al, 1988).

3.6 Exit 33 to Pahrump, on NV 160. At 2:00 are the Wilson Cliffs, massive, light colored cliffs composed of Triassic (?) and Jurassic Aztec Sandstone.

6.4 Railroad crossing (mileage check). Hills at 9:00 are composed principally of Pennsylvanian Bird Spring Formation overlying the Mississippian Monte Cristo Limestone. Blue Diamond Hill is at 2:00.

10.7 High peak at 11:00 is Potosi Peak. Potosi Mountain is underlain by folded and faulted Ordovician to Mississippian carbonate rocks. Lead, silver, and some zinc have been mined in this area.

13.6 Road junction to Blue Diamond and Red Rock Canyon. At 11:00 is blue Diamond Hill where gypsum is mined from four gypsum units in the Lower Permian Kaibab Limestone (Papke, 1986). Based on lithology, presence of redbeds and minor dolomite, and the occurrence of nodular gypsum, the Blue Diamond gypsum deposit is believed to have formed in a sabkha environment. The gypsum is mined in open pits and used for building materials.

15.0 A large outcrop of Tertiary(?) nonmarine limestone occurs at 2:00 (Bohannon and Morris, 1983). Resting on Triassic Moenkopi Formation, Burchfiel and Davis (1988) show this contact as the Bird Spring thrust (see stop 1-1).

19.2 <u>Stop 1-1. Spring Mountains Geology</u>

Three Mesozoic thrust sheets occur along the east front of the Spring Mountains (Burchfiel and Davis, 1988). These thrusts are part of a continuous foreland fold and thrust belt that extends through the United States from Canada to Mexico. In much of the Basin and Range, Cenozoic extensional deformation has obscured the relationships between the thrust systems. However, the Spring Mountains have been little affected by the Cenozoic deformation and provide an opportunity to work out Mesozoic structural relationships.

Three thrust fault systems have been recognized in this area. They have resulted in an estimated 37 to 45 km of shortening (Burchfiel et al., 1974; Burchfiel and Davis, 1988). They are, from east to west, the: 1) Bird Spring, 2) Red Spring-Wilson Cliff-Contact, and 3) Keystone thrust systems. The thrusts systems are higher and younger from east to west (Burchfiel and Davis, 1988).

The Bird Spring fault occurs to the east of the hills northeast of this stop. It appears to be the oldest of the thrust faults and

TABLE 11

PRINCIPAL CENOZOIC VOLCANIC AND SEDIMENTARY UNITS
(modified from Orkild, 1982 et al. 1986

Unit	Inferred Volcanic Center	General Composition	Approx. Age(Ma)
Alluvium	N.A.	Mixed	0 - 6
Younger basalts	Numerous	Basalt (hawaiite)	0.3-7
Thirsty Canyon Tuff	Black Mountain Caldera	Trachytic soda rhyolite	7 - 9
Rhyolite of Shoshone Mountain	Shoshone Mountain	High-silica rhyolite	9
Basalt of Skull Mountain, EMAD	Jackass Flat(?)	Quartz-bearing basaltic andesite	10
Timber Mountain Tuff Intracaldera ash-flow tuffs Ammonia Tanks Member Rainier Mesa Member	Timber Mountain Caldera	Rhyolite to quartz latite	10-12
Paintbrush Tuff Intracaldera ash-flow tuffs Tiva Canyon Member Yucca Mountain Member Pah Canyon Member Topopah Spring Member	Claim Canyon Caldera	Rhyolite to quartz latite	12-13
Wahmonie and Salyer Formations	Wahmonie-Salyer Center	Dacitic tuffs and lavas	13-13.5
Crater Flat Tuff (coeval with Tuffs of Area 20) Prow Pass Member Bullfrog Member Tram Member	Crater Flat(?), Calderas buried under basalt and alluvium	Rhyolite	13.5-14
Stockade Wash Tuff (coeval with Crater Flat Tuff	Silent Canyon Caldera	Rhyolite	14
Belted Range Tuff Grouse Canyon Member Tub Spring Member	Silent Canyon Caldera	Peralkaline rhyolite	14-15
Tuff of Yucca Flat	Uncertain	Rhyolite	15
Redrock Valley Tuff	Uncertain	Rhyolite	16
Fraction Tuff	Cathedral Ridge Caldera	Rhyolite	17
Rocks of Pavit Spring (underlies Crater Flat Tuff)	Dispersed	Tuffaceous sediments	14 ?
Horse Spring Formation	N.A.	Mostly sediments	30

T186:5

marks the western limit of the autochthon of the North American craton (Burchfiel and Davis, 1988). The next thrust system consists of the Red Spring thrust to the north at the base of the La Madre Range; the Wilson Cliffs thrust which occurs at the top of Wilson Cliffs to the northwest; and the Contact thrust to the south of the Cottonwood fault. These three faults are considered by Burchfiel and Davis (1988) to be part of the same system. Mapping by Burchfiel and Royden (1984) has shown that the Keystone thrust occurs above and to the west of the Wilson Cliffs thrust.

The Cottonwood fault is a high-angle northwest-striking fault. While it offsets the Wilson Cliffs-Contact thrusts, it causes warping in the Keystone plate and is considered to be post Keystone by Burchfiel and Davis (1988). At this stop the fault is to the west and passes through the mountain in the canyon the road follows.

To the southwest, dark-gray Cambrian to Pennsylvanian carbonate rocks underlie Potosi Mountain. These rocks form a wedge between the Contact and the Keystone faults. Along the skyline to the south, the Paleozoic rocks are folded into an anticline overturned to the east. Further to the south several other folds rest directly above the Contact thrust.

20.6 In the canyon at 2:00 the Cottonwood fault drops thrusted Paleozoic rocks against the Aztec Sandstone. A small younger fault on the south side of the road places alluvium against Paleozoic limestone.

22.9 Mountain Spring Pass Summit (elev. 5493 ft). Historic marker for Old Spanish Trail. To reach this pass from Las Vegas was a 2 day trip by wagon before the automobile. This trail ran from Santa Fe, NM to Mission San Gabriel near Los Angeles, and was later used by many who went in search of California gold in 1849 and later.

25.7 Spring Mountains at 2:00. Hills at 12:00-1:00 are Mesozoic rocks in normal stratigraphic sequence above Keystone thrust. Ridge of Kaibab Limestone at 1:00. Steeply dipping Bird Spring Formation at 10:00.

27.8 Across Pahrump Valley the Nopah Mountains in California are visible at 10:30-1:00.

36.6 Folded Triassic rocks at 3:00. Red Triassic continental rocks and gray Kaibab Limestone surround a core of Bird Spring Formation in a southward plunging syncline.

38.9 Junction to left with road to Tecopa, CA. At 2:00 Charleston Peak, elevation 11,918 feet, is highest peak in Spring Mountains.

41.1 View of Pahrump Playa at 12:00. Trout Canyon at 3:00. The Lee Canyon thrust (Stop 3-6) emerges from Spring Mountains along the south side of Trout Canyon. Cambrian limestones and dolomites are thrust over Pennsylvanian Bird Spring formation.

42.9 Pahrump, NV at 12:00. At 1:00-2:00 the hill is a doubly plunging anticline of Devonian through Pennsylvanian and Permian carbonate rocks.

47.7 Nye County line. 1:00-3:00 Devonian Sultan Limestone underlying Mississippian Monte Cristo Limestone.

50.4 Dissected lake beds at 3:00.

52.2 Town limits of Pahrump, NV. (Mileage check.)

53.6 Left on Route 372 to west. Nopah Range at 11:00-12:00, and the Resting Spring Range at 12:00-1:00.

60.4 The low hills on both sides of the road are underlain by megabreccia of Bonanza King Formation.

60.6 <u>Stop 1-2 Stewart Valley, Nopah Range, and Resting Spring Range Geology</u>

Bonanza King megabreccia to the northeast, California and the Resting Spring Range across the valley to the west. Northern end of Nopah Range is to the southwest. Chicago Valley is between the ranges. Chicago Pass thrust is best seen on the northern Nopah Range. The jagged topography is underlain by various overturned units of Cambrian through Mississippian carbonate rocks in the Shaw thrust plate described by Burchfiel et al. (1983). The jagged morphology of these gray-weathering carbonate rocks gives way abruptly to the right to smooth, brown-weathering slopes formed by Precambrian and Cambrian clastic rocks of the Chicago Pass thrust plate (Wernicke et al., 1988). The thrust dips shallowly off to the north between these two units. Wernicke et al. (1988) correlate this thrust with the Wheeler Pass thrust in the Spring Mountains. Both thrusts place Precambrian clastic rocks on Bird Spring strata, a stratigraphic throw of about 5000 m. Continue northwest on Stewart Valley road.

62.4 At 3:00 Late Proterozoic Stirling Quartzite (reddish brown) in fault contact with small hill of gray Bonanza King megabreccia.

65.2 Wood Canyon Formation (dark reddish brown) at 3:00. Behind and to the north, with vertical, light-colored fissure fillings, and forming the high jagged hills is the Bonanza King Formation .

67.4 Wood Canyon Formation-Stirling Quartzite contact at 10:00. Both Wood Canyon and Stirling Quartzite form smooth rounded hills. The high peak is Shadow Mountain, the northernmost part of Resting Spring Range.

70.7 Road junction, left at fork. Hill at 2:00 is Bonanza King Formation dipping 30° to west. Amargosa Valley at 12:00.

73.5 Tertiary tuffaceous sediments in hill at 3:00. Smooth hills to southwest (9:00) are underlain by Wood Canyon Formation and Stirling Quartzite.

75.0 On both sides of the road light-green altered tuffaceous sediments, capped by Quaternary alluvium. The Tertiary tuffaceous sediments are commonly composed of ash-fall tuffs and tuffaceous sedimentary rocks. Low temperature ground-water alteration is widespread; clinoptilolite (zeolite) the most common alteration product.

77.9 Junction, turn right.

78.6 Keep to the left at the clay pit with altered green tuffaceous sediments.

79.1 Sign to East/West Minerals, proceed straight ahead. Southern end of Ash Meadows spring system at 3:00. Ash Meadows Ranch on the right.

79.7 Tuff mounds on both sides of road. Funeral Mountains across valley (9:00).

82.1 Junction, turn right at T. Point of Rocks Ridge, at 3:00, is underlain by the Banded Mountain Member of the Bonanza King Formation.

83.4 Turnoff to Devils Hole to left (west).

83.5 <u>Stop 1-3. Devils Hole Geology and Hydrology</u>

The Devils Hole area is located within a series of northwest-striking steep ridges of Bonanza King Formation that are controlled by northwest-striking folds and faults in the Paleozoic rocks (Carr, 1988). Although northwesterly trending structural grain is the most prominent trend in the area, small faults and fractures of northeast strike are the most important hydrologically. They control the location of Devils Hole, other collapse depressions and the orientation of calcite veins in the bedrock.

From general relationships in the area, it is concluded that most of the structural disturbances occurred well before about 4 Ma, but establishing the age of undated older Tertiary rocks in and near Ash Meadows is critical to dating the periods of important structural activity. The openings at Devils Hole considered together with orientation of the sinkholes, fractures, and faults in the surrounding area, are, in accord with a general stress field model (Carr, 1974, 1984) for this part of the Great Basin. In the last 5 million years or so the minimum principal stress direction has been oriented northwest-southeast according to Carr's model. Faults and fractures of northwest strike would tend to be closed, whereas those of northeast strike would tend to open. The youthful appearance of some of these features suggests that the proposed stresses are currently active.

The depressions in carbonate rock range from holes or shallow depressions approximately 0.3 m in diameter, to Devils Hole, which is an opening approximately 22.7 m by 7.6 m in plan view and 15.2 m deep. Devils Hole is the only such feature in the Ash Meadows area whose subsurface extent is even partially known. According to Alan C. Riggs (U.S. Geological Survey, written commun., 1985; 1986), Devils Hole extends to more than 300 feet below the water table, and a network of passages extends at least 91.4 m to the northeast, including an uncollapsed subterranean opening above the water table called "Brown's room". The average width of the passageways is about 1.8 m.

The passageways and room walls seem to be largely controlled by fault planes. Riggs (U.S. Geological Survey, written commun., 1985) reports that, near the north-eastern end of "Brown's room", a chimney extends about 15.2 m above the water table, which is at an altitude of about 719 m. Surface elevation above this point is estimated to be about 739 m, so that the room probably comes to within about 3.0 or 4.6 m of the ground surface, yet no sign of surface collapse is evident. It is believed that most of the structural displacements in the Devils Hole area occurred well before about 4 Ma.

The Devils Hole area is highly transmissive hydrologically as evidenced by the large discharge of water from many springs in the Ash Meadows area (Winograd and Thordarson, 1975). Winograd and Pearson (1976) discussed an important carbon-14 anomaly in the age of water being discharged from the larger springs. Briefly, they found that water from all but one of the springs had a similar carbon-14 content (about 2.4-percent modern), whereas one of the largest springs, Crystal Pool had a carbon-14 content almost 5 times larger (about 11.1 percent modern) than all the other spring waters analyzed. They conclude that water discharging from Crystal Pool is following a preferred pathway from recharge areas many miles to the northeast. This pathway enables the water to move much more rapidly than water reaching other springs. Because Crystal Pool is centrally located within the discharge zone, it is likely that a natural pipeline or "megachannel" is located relatively near the discharge area. Furthermore, the flow direction is probably from the northeast (Winograd and Thordarson, 1975), a direction normal to the alignment of larger springs at the spring line, so that the ground water that discharges at Crystal Pool must pass through the Devils Hole area. The top of the regional lower clastic aquitard (Winograd and Thordarson, 1975) is about 1,067 m below the water table in the Devils Hole area.

83.7 Return to road and turn left (north) on Ash Meadows-Crystal Road. The hills on both sides of the road are Bonanza King Formation.

85.7 Summit-Amargosa Flat and Specter Range at 12:00, Spring Mountains at 2:00.

87.6 Stop 1-4 Amargosa Desert clay deposits

The Amargosa Desert is an intermontane basin that drains southward. It is underlain and nearly surrounded by highly folded and faulted Paleozoic rocks such as were seen at and between the earlier stops. To the northwest the basin is bordered by Miocene volcanic rocks. These basement rocks are overlain by an assemblage of moderately to highly deformed fanglomerates, siltstones, limestones, and tuffs that have been correlated with the Upper Miocene Furnace Creek Formation of Death Valley (Naff, 1973). Unconformably overlying these rocks are slightly deformed Pliocene and Pleistocene sediments that fill the present geographic basin (Hay et al., 1986). These deposits consist largely of spring related carbonate rocks, Mg clays, and detrital montmorillonite-rich claystones. Poorly indurated clastic and calcareous sediments occur in the west central and northern parts of the basin.

The Pliocene Mg clay deposits of the Amargosa Desert are the largest known deposits in the western United States (Hay et al., 1986). These 2.3-3.2 Ma sediments were deposited in flood plains, marshlands, ponds, and playas. Three laterally equivalent lithofacies were recognized by Pexton (1984). One lithofacies occurs within 1 to 2 km of the Paleozoic hills to the south of this stop. This facies is characterized by a continuous belt of limestones with interbedded clay. The limestones were precipitated in marshlands and ponds fed by springs in Paleozoic hills to the south. Hay et al. (1986), interpret the distribution of limestone to indicate perennially wet conditions near the Paleozoic carbonate hills grading outward into an area in which wet and dry conditions alternated.

The second facies consists largely of claystones and limestones. The major clay mineral is detrital montmorillonite that was derived from the volcanic rocks to the north (Hay et al., 1986). These sediments occur to the west of the first facies, and are its basinward extension.

The third facies occurs north of the first facies and represent playa and marshland environments. This facies is characterized by Mg clay, limestones, and dolomites. Mg smectite is the dominant clay mineral. Deposits of relatively pure sepiolite occur within this facies, such as at this stop. Authigenic illite and K-feldspar and oxygen isotope data (Hay et al., 1986) indicate the water in the playa was saline and alkaline and resulted from evaporation. Sepiolite deposited from low salinity water is found in or near areas of spring discharge.

The distribution, mineralogy, and geochemistry of these clay deposits suggest that in the Pliocene springs were more widespread and had greater discharge. This wetter period ended about 2.5 Ma. Return to Ash Meadows-Crystal road and turn north.

88.6 Turn left (west), onto private road, drive with caution, watch for trucks.

88.2 Specter Range to north. Darker colored, lower Paleozoic formations to west; to east Silurian carbonate rocks form light colored, higher hills. Funeral Mountains 12:00, Death Valley is on west side of mountains.

95.6 Fairbanks Spring at 9:00 is the northernmost spring of the Ash Meadows spring system.

100.8 Junction with State Route 29 turn right (north). Highway to left goes to Death Valley Junction, CA, and to Death Valley via Furnace Creek Wash.

113.7 Stop 1-5 Geology southern portion of NTS

Stop is at a roadside park in Village of Amargosa Valley, NV, formerly Lathrop Wells, NV. To the northwest is Yucca Mountain, site for the proposed high level nuclear waste repository. Skyline behind Yucca Mountain is Pinnacles Ridge, which forms the south rim of the Timber Mountain caldera. Also visible are Fortymile Wash, east of Yucca Mountain, and the varicolored volcanic rocks of the Calico Hills further to the east.

The southwestern Nevada volcanic field is a complex assemblage of rocks covering an area of several thousand square miles, mainly in southern Nye County. Most of these rocks are silicic ash-flow tuffs. The central area of the field is a normally faulted and dissected volcanic plateau of about 2,500 mi^2 (6,475 km^2) that extends north from the village of Amargosa Valley. Several volcanic centers have been located in the southwestern Nevada volcanic field; and those associated with the large-volume ash-flow units generally are collapse calderas. Calderas in the immediate vicinity of the NTS include Silent Canyon caldera, Crater Flat caldera, Claim Canyon caldera, the Timber Mountain caldera, and the Black Mountain caldera (FIGURE 2). Collectively, greater than 3000 km^3 of tuff originated from these calderas. Several other calderas in the surrounding region have been described by various investigators.

The Tertiary volcanic section of the southwestern Nevada volcanic field includes many units. One needs to be familiar with only a few of these units for the purposes of this trip, but Table II lists all the major Tertiary units of the NTS area for general reference. Major units related to the same volcanic centers and having mappable lithologic and petrographic similarities are named as formations; individual ash-flow cooling units (ignimbrites) are designated as members.

117.0 Fortymile Wash crosses U.S. 95. To left at 11:00 is Big Dune composed of eolian sand.

119.3 Southernmost end of Yucca Mountain just north of U.S. 95 on right. Outcrops are Miocene Paintbrush and Crater Flat Tuffs repeated by northeast-striking faults.

120.2 Lathrop Wells cinder cone at 3:00. (Stop 2-1.)

121.2 Outcrop of vitrophyre in Miocene Rainier Mesa Member of Timber

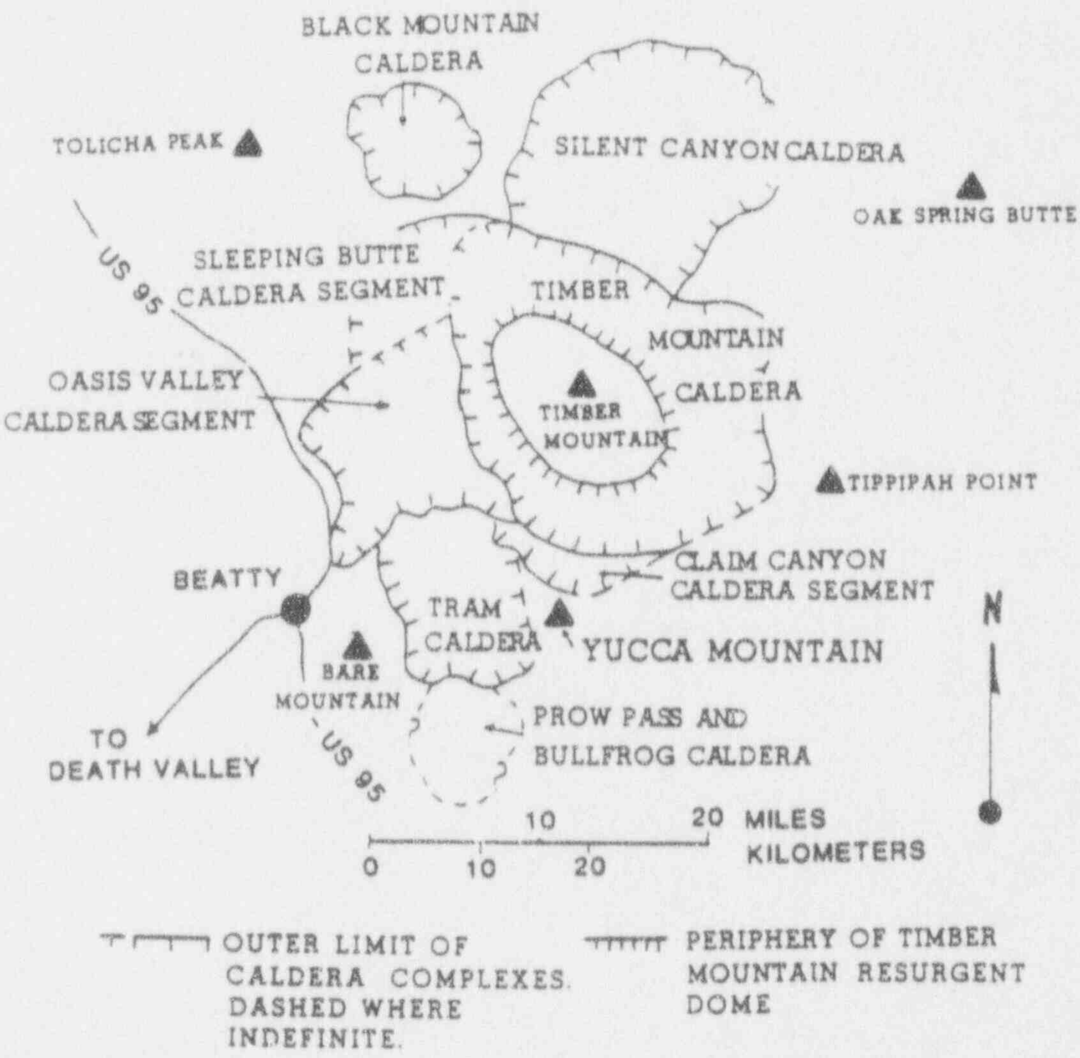


FIGURE 2. Map showing outline of calderas in southwestern Nevada volcanic field. Stonewall Mountain northwest of Black Mountain caldera is not shown. Modified from Dockery et al., 1985, Figure 2.

Mountain Tuff at 3:00.

122.7 Crater Flat is to the north, Yucca Mountain is at 3:30, the south wall of Timber Mountain caldera is on skyline at 3:00.

124.4 Hills are composed of monolithologic megabreccia of the Cambrian Bonanza King Formation on top of Miocene tuffs.

128.8 Junction to right with road to Crater Flat through Steves Pass. At 2:00 is south end of Bare Mountain. Low rounded foothills, are underlain by Stirling Quartzite, Wood Canyon Formation, and Zabriskie Quartzite. The latter underlies Wildcat Peak. Mountain at 4:00 is a slide block, from Bare Mountain, of Cambrian Bonanza King Formation overlying Miocene tuffs.

131.4 At 9:00 - U.S. Ecology "Low Level Radioactive Waste Repository". The Beatty, NV disposal site was the first licensed commercial disposal site in the United States (Clancy, et al., 1981). The site, licensed by the U.S. Atomic Energy Commission in 1962, is owned by the State of Nevada and operated by U.S. Ecology, Inc. The site is 80 acres and includes a non-radioactive chemical waste site adjacent to the low-level radioactive waste site.

The valley floor is alluvium composed of detritus from the surrounding mountain ranges. Based on a drill hole and surface gravity measurements, the alluvium is estimated to be 175 m thick (Clebsch, 1962, Nichols, 1987). The bedrock is probably Paleozoic formations, similar to those at Bare Mountain to the north.

The principal drainage is the Amargosa River, which is dry most of the year. Average annual rainfall is from 63.5 to 127 mm, but can range from 22 mm to 250 mm (Clancy et al., 1981).

The low-level waste has generally been disposed at the site by means of a cut-and-cover trench operation. The dimensions of trenches are variable with lengths from 91.4 to 198.1 m, widths from 1.2 to 27.4 m and depths from 1.8 to 9.1 m (Clancy et al., 1981). A minimum of 0.3 m of cover is required above the waste. In addition, the trench cover must be mounded to provide drainage away from the trenches.

135.1 Road to Carrara townsite at 3:00. In the early 1900s marble quarries were established at Carrara. The marble was too strongly fractured and weathered to be marketable. A complete, north dipping Proterozoic and Paleozoic miogeosynclinal section is exposed along the range.

138.8 Beatty Mountain at 12:30.

139.5 Beatty scarp at 3:00. Trenching across the 7 km long lineament has not revealed a fault, and has been attributed to erosional processes, based on mapping and geophysical data (Swadley et al., 1987).

140.2 Left turn on road to Beatty airport.

143.4 Intersection with Nevada 58 between Beatty and Death Valley. Turn left.

145.2 Road to Rhyolite - right turn from Nevada 58.

149.0 Road to left. Remnants of buildings and dwellings to north are the historic town sites of Bullfrog and Rhyolite.

150.5 Road to right, go west.

152.6 Y, go to west.

153.1 Junction, go left, mine and exploration workings for gold are preserved on hills and slopes north of road.

155.0 Junction, go to left on old railroad right of way.

155.6 Heap leach to left. Piles of 1-5 cm size crushed ore are treated with cyanide solution to leach out gold.

155.7 Entering Death Valley Monument (mileage check).

155.9 <u>Stop 1-6 Original Bullfrog mine</u>

This mine was discovered in 1904 and described by Ransome et al. (1910). At this stop a metamorphic core complex and associated low-angle detachment faults can be seen. Along the south side of the Bullfrog Hills the extended terrain contains at least two proposed detachment faults. At this stop the upper detachment fault separates a middle plate composed of a highly attenuated incomplete sequence of lower and middle Paleozoic clastic and carbonate rocks from an overlying sequence of block-faulted Miocene volcanic, volcaniclastic, and sedimentary rocks (Maldonado, U.S.G.S. 1988, private comm.). A proposed lower detachment fault, not exposed at this stop, separates the middle plate from a lower plate(?) of amphibolite grade metamorphic rocks. These Proterozoic rocks are exposed in the hills approximately 1 mile southwest of this stop. These rocks consist of quartzofeldspathic gneiss, biotite schist, marble, and amphibolite, all cut by granitic pegmatites. These rocks have tentatively been correlated with the Johnnie Formation (Table I). K-Ar age on minerals from these rocks suggest the uplift and cooling of the metamorphic complex occurred during the late Miocene (16.3-10.5 Ma).

The Miocene rocks of the upper plate dip moderately to steeply to the east into the upper detachment, or where the middle plate is not present into the lower detachment. The Miocene rocks are repeatedly faulted and tilted resulting in a terrain extended generally more than 100 percent and locally more than 200 percent. These detachment surfaces have been mapped 22.5 km to the east along the north side of Bare Mountain. East of Beatty, NV this fault is called the Fluorspar Canyon fault. The faulting of a 6.5 Ma tuff in the upper plate suggests the extensional faulting occurred as recently as 6.5 Ma. As noted earlier, the uplift and cooling of the metamorphic core complex occurred between 16.3 and 10.5 Ma. Thus the period of extension appears to have extended at least from 16.5 to 6.5 Ma. The recent discovery of economic amounts of finely disseminated gold in the Miocene tuffs and Paleozoic carbonate rocks above and below the detachment has revived the mining interest in this area. Return to Nevada 58.

162.4 Junction with Nevada 58, turn left.

166.1 Third and Main, Beatty, NV, turn right, proceed south on U.S. 95.

167.4 Amargosa Narrows, turn left on Fluorspar Canyon road, proceed across the Amargosa River on graded dirt road.

168.0 Outcrop of Cretaceous granitic sill. Turn to left.

168.4 Stop 1-7 Fluorspar Canyon fault. The Fluorspar Canyon fault passes through the saddle on the south flank of Beatty Mountain, approximately 100 m west of the mine road (Carr and Monsen, 1988).

A gently dipping fault (25° N) is proposed separating middle Miocene volcanic and sedimentary rocks above from the underlying late Proterozoic and Cambrian metasedimentary rocks. An exhumed surface on top of the carbonate rocks south of the saddle reflects the approximate attitude of the fault. In the hanging wall plate of the fault, Miocene volcanic rocks are tilted eastward in blocks bounded by moderately to steeply northwest-dipping faults. The faults in the hanging wall plate are postulated to terminate at or merge with the low-angle Fluorspar Canyon fault at depth.

Rocks in the footwall are part of a structurally attenuated section of late Proterozoic and Cambrian metasedimentary rocks, better exposed in Conejo Canyon to the east (Carr and Monsen, 1988). These rocks dip northward in normal stratigraphic order, but large intervals of the stratigraphic section have been cut out along low-angle faults that nearly parallel bedding. The uppermost of these units (Middle Cambrian carbonate rocks) has been intruded by a granitic sill, which is dated as Cretaceous on the basis of U-Th-Pb age data from included zircon (Carr and Monsen, 1988).

According to Carr and Monsen (1988) the Fluorspar Canyon fault is part of a regional, low-angle normal fault system that propagated to the land surface in the Bare Mountain area during the late Miocene. The fault projects westward across the Amargosa Narrows, where it continues as the low-angle Original Bullfrog fault (Ransome et al. 1910) at the base of the extended Tertiary volcanic terrane of the Bullfrog Hills (Stop 1-6). The fault is proposed to extend eastward to the head of Fluorspar Canyon. Return to road.

168.7 Turn left up canyon.

171.3 Left turn. At 12:00 is Daisy Fluorspar Mine. The fluorspar deposit occurs in dolomite of the Nopah Formation (Cornwall and Kleinhampl, 1961).

171.6 Bullfrog Member of Crater Flat Tuff to left - across fault.

172.3 Road to left goes to Crater Flat.

172.6 Stop 1-8 Extended Terrane North

of Fluorspar Canyon Fault (Optional)

At this stop we can view the extensional terrane above the Fluorspar Canyon fault to the north (Carr and Monsen, 1988). The small ridge of volcanic rocks to the north contains a conformable or paraconformable sequence of middle Miocene tuff and tuffaceous sedimentary units, dipping moderately eastward. To the northeast, this section flattens beneath the volcanic mesas that lead to the Timber Mountain caldera; the rugged terrain on the northeastern horizon. The middle Miocene geomorphology seems only slightly modified in that area. To the northwest, the same middle Miocene section forms the jumble of fault-bounded blocks that are tilted eastward along northwestward-dipping faults in the upper plate of the Fluorspar Canyon fault. The youngest rocks affected by this faulting are basalt inferred to be 10.5 Ma by Carr (1984). The basalt is apparently conformable with the sequence of middle Miocene ash-flow tuffs.

Nearly flat-lying alluvial fan deposits, which are inferred to be late Miocene materials on the basis of their similarity to isotopically dated deposits east of Bare Mountain (7.7-8.7 Ma, J. K. Nakata, written commun., 1986, in Carr and Monsen, 1988), lap unconformably over the strongly faulted and tilted middle Miocene rocks north of Bare Mountain. These relationships suggest that much, if not all, of the extension above the Fluorspar Canyon fault occurred between about 10.5 and 7.5 Ma in the Bare Mountain area. The boundary between the strongly deformed extensional terrane to the northwest and the less-deformed plateau to the northeast is the fault on the west side of the small ridge north of this stop. This fault is interpreted as part of the breakaway for the Grapevine-Bullfrog-northern Bare Mountain extensional allochthon. Retrace route back to Beatty.

END DAY 1

Second Day Beatty, NV to Yucca Mountain
mileage (cumulative)

0.0 Leave Burro Inn travel east from Beatty on Highway 95

0.9 Amargosa Narrows, Fluorspar Canyon turn off

2.0 Original Bullfrog/Fluorspar Canyon detachment fault is near base of hills at 3:00

2.4 Airport Road (mileage check)

10.2 See mile 131.4 first day.

12.8 Road to Crater Flat. At 10:00 gravity slide of Bonanza King Formation from Bare Mountain, sitting on Tertiary sediments.

16.6 Lake beds containing camel and mastadon fossils at 10:00.

18.6 View of Yucca Mt at 9:30

19.6 Type locality of Crater Flat Tuff (slow drive by). Miocene volcanic units and type locality of the Crater Flat Tuff (Dockery et al., 1985). This section from base upward consists of: (1) vitric ash-fall tuffs overlain by (2) a boulder debris flow (yellowish-green layers near base of hill), (3) Bullfrog Member (dark vitrophyre near base) and Prow Pass Member of the Crater Flat Tuff, and (4) Topopah Spring and Tiva Canyon Members of the Paintbrush Tuff (on skyline). This is the only known section where the Crater Flat Tuff is vitric and unaltered; the Tram Member, the oldest unit, is missing here.

20.3 Southernmost end of Yucca Mountain just north of U.S. 95 on left. Outcrops are Miocene Paintbrush and Crater Flat Tuffs (see Table II) repeated by northeast-striking faults.

21.3 Stop 2-1 Lathrop Wells cinder cone (Road side stop) The Crater Flat area (also see Stop 2-4) contains over 15 small basaltic volcanic centers composed of cinder cones and associated lava flows. Only the youngest center is visible at this stop. The distribution, petrology, and tectonic setting of the basalts have been described by Crowe and Carr (1980), Vaniman and Crowe (1981), Vaniman et al. (1982), Crowe et al. (1982), and Crowe et al. (1983a and 1983b). The rocks are divided into three eruptive cycles based on geologic field relations, potassium-argon ages, and magnetic polarity determinations. The K-Ar ages listed below were done by R. J. Fleck, USGS (written commun., 1979, in Dockery et al., 1985) and R. F. Marvin, USGS (written commun., 1980, in Dockery et al. 1985).

o 3.7-m.y. cycle Rocks of the oldest cycle consist of deeply dissected cones and flows with locally exposed feeder dikes. They occur in the central and southeastern part of Crater Flat (Fig. 1).

o 1.2-m.y. cycle (Qb) Basaltic rocks of this cycle consist of cinder cones and lava flows located along a northeast, slightly arcuate trend near the center of Crater Flat (Fig. 1) From northeast to southwest, the major centers in this cycle include unnamed cone, Black, Red, and Little Cones.

o 100,000 yr cycle (Qb) The youngest cycle is marked by essentially undissected cones and flows of the Lathrop Wells center.

The Lathrop Wells volcanic center is the youngest basalt center in the Yucca Mountain region and is believed to be 20,000 yrs or less in age (Wells et al., 1988; Crowe and Turrin, in prep). It consists of blocky aa lava flows that were erupted from multiple sources along three fissures. These include two en echelon northwest-trending fissures located northeast of the scoria cone and a third east-northeast trending fissure located north of the scoria cone. The main scoria cone overlies the fissure- and lava-flow units. Tephra from the youngest eruptions of the main scoria cone overlie small satellite scoria cones that have mostly been removed by quarrying activity. Pyroclastic surge deposits are present throughout the main scoria cone sequence and along the northwest and southeast flanks of the scoria cone. They also are locally present among the older fissure deposits indicating episodes of hydrovolcanic activity throughout the eruptive stages of the center.

The age of the volcanic center has proven to be problematic. Whole rock, K-Ar age determinations of samples of the lava flows have yielded ages that range from 730,000 to 8,000 yrs B.P. (Sinnock and Easterling, 1983). The inconsistent results are thought to be from a variable component of excess Ar and accordingly the youngest ages may represent the true age of the lavas (40,000 to 70,000 yrs B.P.). Several lines of evidence indicate the main scoria cone is significantly younger than the lavas and may be as young as or younger than 20,000 yrs B.P. This evidence includes: 1) smooth, unrilled cone slopes, 2) lack of development of a cone-slope apron, 3) poor development of soils on the cone slopes, 4) presence of local soil zones between deposits of the scoria cone and older lavas, and 5) differing measured paleomagnetic pole positions for the scoria cone and the lavas. These data require a polycyclic origin (multiple eruptions separated by significant time intervals) for the Lathrop Wells volcanic center.

The ages of the Quaternary alluvial deposits are consistent with ages for the basalt. Before the eruptions, alluvium of middle Pleistocene age locally developed a dense K-horizon that gave a uranium series age of about 345,000 yr B.P. The pyroclastic material became incorporated locally in upper Pleistocene alluvium, and a loessial silt deposit accumulated on the cinder cone and regionally on the Q2 alluvium before about 25,000 yr ago.

The structural control for the location of the center is not obvious. The cone, summit crater, satellite cones and fissure systems are aligned northwesterly, probably due to northwest-trending structural control. Faults striking north-northeast are also present though poorly exposed. The center is located on a regional northeast-trending structural lineament marking the western edge of the Spotted Range-Mine Mountain northeast-trending structural zone (Fig. 1); faults west of this lineament have a more northerly trend. It is suggested that the strike of the faults influenced the location of the Lathrop Wells center; that is, the eruptions were fed from dikes whose trends were controlled by the regional stress field, with a NE least compressive stress direction.

The basalts of the Lathrop Wells center are sparsely porphyritic with olivine as the major phenocryst phase (3 modal percent). They differ from the 1.2-m.y. cycle basalts by having a slightly greater olivine content and a greater amount of unaltered basalt glass. Also the cores of olivine phenocrysts are slightly more forsteritic (FO_{80-77}) than olivines of the 1.2-m.y. cycle (FO_{77-76}), as determined by electron microprobe analysis. Ground mass phases also include plagioclase (zoned from An_{68} to more alkaline compositions) and minor amounts of olivine, pyroxene, and iron-titanium oxides plus interstitial glass. Textures of the basalts of the Lathrop Wells center are hyalopilitic to pilotaxitic. A detailed discussion of the mineralogy and geochemistry of the Lathrop Wells center is found in Vaniman and Crowe (1981) and Vaniman et al. (1982).

22.2 South end of Yucca Mt.

Specter Range	12:00
Spring Mountains	1:00
Rock Valley	11:00
Funeral Mountains	3:00-4:10
Calico Hills	9:00-9:30
Amargosa Valley	2:00-3:00
Yucca Mountain	8:00-8:30

24.7 Fortymile Wash.

27.2 Road to NTS, turn left.

28.2 Striped Hills 3:00, Little Skull Mt 2:00.

29.1 Entrance to NTS through Lathrop Wells guard gate. Badge check.

33.2 At approximately 3:00 view Little Skull Mountain, capped by Miocene (approximately 10 Ma., R. F. Marvin, USGS, written commun., 1980 in Dockery et al., 1985) basalt of Skull Mountain, underlain by faulted Miocene Topopah Spring Member of the Paintbrush Tuff and tuffs of the Wahmonie Formation. Low hills at foot of mountain contain outcrops of the Tram and Bullfrog Members of the Crater Flat Tuff. Busted Butte at 10:00 is a complete section of the Topopah Spring Member overlain by Tiva Canyon Member of the Paintbrush Tuff. Low, white water tank is at Well J-12 at the edge of Fortymile Wash. Long ridge on skyline to northwest 11:00 is Yucca Mountain.

37.1 Low hills at 10:00 are Topopah Spring Member capped by 9.6 Ma. basalt of EMAD (R. F. Marvin, USGS, written commun., 1980, in Dockery et al., 1985).

38.5 North side of Skull Mountain at 1:30. From top to bottom is basalt of Skull Mountain, Rainier Mesa Member of Timber Mountain Tuff, Topopah Spring Member of Paintbrush Tuff, and Wahmonie lavas.

40.7 Turn left onto road next to the Nevada Research and Development Area (NRDA) facility.

40.8 Stop 2-2 DOE Sample Management Facility (SMF)

The U.S. Department of Energy (DOE) operates a state-of-the-art SMF which processes, documents, and preserves Yucca Mountain Project geologic samples to satisfy quality assurance requirements for licensing a geologic repository. The SMF includes the physical facility designed to process and preserve those samples, as well as management, quality assurance, and operations staff. One of the SMF's primary responsibilities is to document the life cycle of a sample from the time it is collected in the field, through transport, processing, analysis, and storage.

The SMF staff includes a manager, a curator, a facilities geologist, a field operations manager, several geotechnicians, and other support staff which are experienced and trained in sample management and quality assurance (QA) code and standards. The SMF is operated by Science Applications International Corporation, the current Technical and Management Support Services contractor.

42.3 On skyline at 12:00 Shoshone Mountain is capped by 8.9 Ma. rhyolite lavas (R. F. Marvin, USGS, written commun., 1980, in Dockery et al, 1985).

42.8 Turn left and proceed west toward Yucca Mountain.

43.4 At 9:00 is the Engine Maintenance, Assembly and Disassembly (EMAD) facility to left. Originally used for nuclear rocket engine maintenance, now operated by Westinghouse for handling and temporary storage of nuclear waste.

43.9 Rocket assembly facility at 3:00, one of several built in conjunction with Nuclear Rocket Development Station in 1960s.

46.9 Busted Butte at 11:00.

48.4 Road to water Well J-13. Fran Ridge at 12:00 is composed of Topopah Spring Member, overlain by light-colored bedded tuff and Tiva

Canyon Member.

48.6 Crossing Fortymile Wash.

49.1 Turn left at sign for drill hole USW G-3.

51.3 Round southern end of Fran Ridge. To south at 9:00 is Busted Butte composed of Paintbrush Tuff cut by a narrow structural slice containing parts of the entire Tiva anyon Member. Dips range from steeply westward to overturned within a 100-m-wide zone. On the right, along the wash, are exposures of Topopah Spring Member with lithophysal cavities and north-northwest-striking fractures.

51.6 On the skyline at 10:00 is Yucca Crest, at 12:30 Boundary Ridge, at 2:00 Bow Ridge, at 2:45 P-1 Hill, and at 3:30 Fran Ridge, all exposing the Paintbrush tuff. Ridges are created by west-dipping major normal faults on west side of each ridge. Strata underlying ridges dip eastward; major normal faults are accompanied by highly brecciated and steep west-dipping strata.

53.2 To right along Boundary Ridge, a 20° angular unconformity exists between 11.3 Ma. Rainier Mesa Member and the underlying 12.6 Ma. Tiva Canyon Member (Marvin and others, 1970). Rainier Mesa Member laps across major faults with only minor displacement.

53.8 Road to Well WT 1.

54.0 The generalized map and accompanying detailed geologic section (FIGURE 3) show this part of Yucca Mountain to consist of a series of north-trending, eastward-tilted structural blocks, repeated by west-dipping normal faults. West-dipping strata along these normal faults are interpreted as the result of shear along the fault planes. On Yucca Crest strata dip eastward at 5° to 7°; however, to the east strata also dip eastward, but commonly from 20° to vertical. Coincident with the dips greater than 20° are abundant west-southwest-dipping faults with 1 m to 5 m of vertical displacement. These faults and related fractures are nearly perpendicular to foliations in the tuff, suggesting rotation. In addition to required rotation of the fault planes and intervening blocks, graben-like features suggest a geometric control by the shape of major normal faults. The dip of major faults decreases from the average of 70° at the surface to 60° at depth as suggested by data from some drill holes. On Busted Butte, rotated fault slices extend to depths greater than 200 m; if this geometry is typical, then any decrease in dip on the major normal faults must occur at greater depths.

55.2 Crest of Yucca Mountain, turn left.

55.6 Stop 2-3 Overview Regional Geology

Most of the areas and locations discussed can be found on FIGURE 1. To the north is the rim of the Timber Mountain and Oasis Valley nested caldera complex (FIGURE 2). This caldera complex was active from approximately 9-17 m.y. with silicic volcanism active to approximately 7 Ma. in the general region. The tuffs at Yucca Mountain were erupted from this nested volcanic center. Yucca Mountain consists of the north-south ridge upon which you are standing and the east-west continuation of this ridge to the north.

To the northeast are the Calico Hills, a domal structure with Tertiary tuff units overlying Paleozoic strata of the Eleana Formation. From this location the tuff units can be observed dipping to the west and south. The rocks at the Calico Hills can be highly altered. They lie along a linear east-west magnetic high trending across the northern top of Yucca Mountain for 10-25 km. The magnetic high may represent a pluton at depth (Carr, 1984) or may represent the formation of conductors (magnetite) in the metamorphosed Mississippian Eleana Formation (Bath and Jahren, 1984).

Jackass Flats is the broad alluvial valley to the east which leads into the larger east-west trending Amargosa Valley to the south. To the east-northeast in the background, the Wahmonie area (Lookout Peak) and volcanic center consists of basaltic, andesitic, and silicic volcanics erupted more than 13 Ma. To the southeast in the distance are Skull Mountain and Little Skull Mountain which are composed of Miocene tuffs capped by 8 Ma. basalts. To the east in the foreground, the rocks comprising the

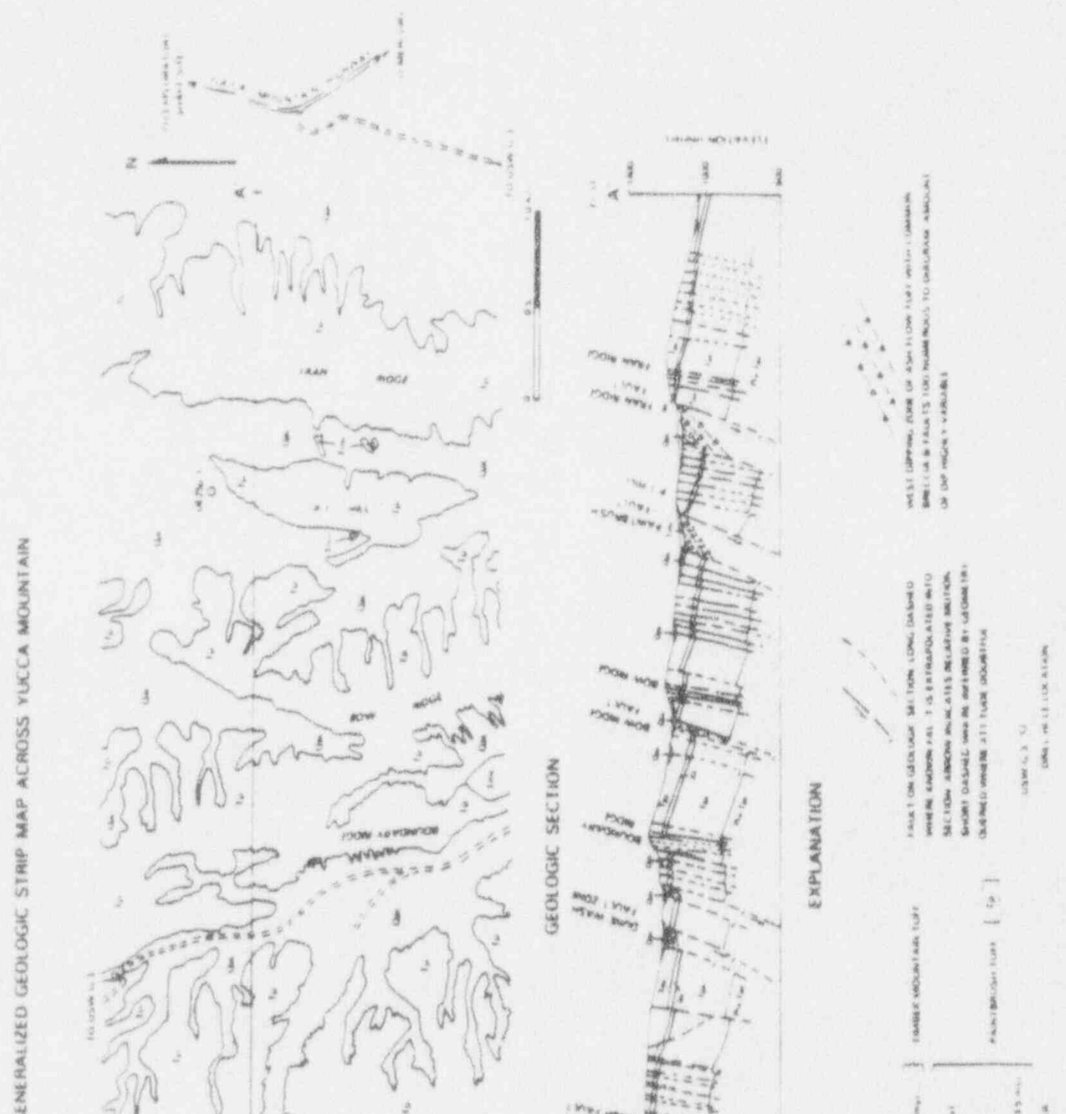


FIGURE 3. Geology of a part of Yucca Mountain area. After Dockery et al. 1985, Figure 7.

north-south trending Fran Ridge and Busted Butte to the southeast are of comparable age and stratigraphy to the tuffs at Yucca Mountain. Just beyond Busted Butte and Fran Ridge, Fortymile Wash can be seen. The surface facilities for the site are planned to be located in the small valley in the foreground between the north end of Fran Ridge and the base of Yucca Mountain.

To the southwest, in the distance, the Funeral Mountains can be observed. These mountains consist of Paleozoic rocks with complex structural features. On a clear day one can see the crest of the Sierra Nevada Range (over 100 miles to the west). The alluvial valley to the west is Crater Flat and in the distance Bare Mountain. Crater Flat has been proposed to be an ancient caldera (Carr et al., 1986), a valley bounded by classical Great Basin normal faults, or underlain by a detachment fault (Scott, 1986). Basaltic cinder cones of about 1.1 Ma. occur in the central part of the Crater Flat. Eroded remnants of 3.7 m.y. old volcanos occur in the southeastern part of Crater Flat. Bare Mountain, due west, is a complexly faulted (normal and thrust faults) and folded terrane composed of Paleozoic carbonate rocks, dolomites, and shales. There is approximately 600 ft of relief from where you are standing to the valley in Solitario Canyon immediately to the east. The west side of Yucca Mountain is bounded by the North-trending Solitario Canyon fault.

As described at Stop 2-1 there are several low-volume basaltic cinder cones and lava flows of "weak" alkalic series affinity (Vaniman et al., 1982; Crowe et al., 1983a) located in Crater Flat and at the south end of Yucca Mountain. These volcanic features range in age from 3.7 Ma. to as young as 20,000 years B.P. These low-volume basaltic eruptions are part of a larger several hundred kilometer long linear belt of volcanism trending north-northeast from south-central Nevada (Lunar Crater field) to Death Valley, CA; the Death Valley-Pancake Range zone (e.g., Crowe et al., 1986; Vaniman et al., 1982). To the west and southwest of where you are standing, the cinder cones are Black Cone, Red Cone, and Little Cone and these form a northeast-trending arc in conjunction with the lava flows and other cinder cones in the area. The top of the Lathrop Wells basaltic cinder cone (Stop 2-1) should be visible to the south. The basaltic volcanism near Yucca Mountain has exhibited a decrease in the eruptive volume with time and a progressive shift to the southwest with time (Crowe et al., 1983b, 1986). Multiple studies have been performed to assess the nature and significance these basaltic eruptions could have on waste isolation (Crowe and Carr, 1980: Crowe et al., 1982, 1983a, 1983b, 1986). Three additional studies are planned to be completed during site characterization (U.S. Department of Energy, 1988).

56.7 Well USW G-3 and GU-3, turn around and go north.

58.1 Road to crest of Yucca Mountain to right continue north.

59.1 Stop 2-4 Overview Yucca Mountain Geology and High Level Nuclear Waste Repository

The rocks at Yucca Mountain consist of a gently eastward dipping sequence (1,800 m thick) of Miocene ash-flow tuffs, lava flows, and volcanic breccias intercalated with relatively thin volcaniclastic rocks and air-fall tuffs (Table II). This sequence is flanked by younger alluvial deposits. The stratigraphy below 1,800 m is inferred from geophysical data and the interpolation and extrapolation of information from the surrounding region. Estimates of the depth to subvolcanic surface (the unconformity between the Tertiary volcanic rocks and the Paleozoic rocks) ranges from 1,200 m beneath the southeastern portion of Yucca Mountain (drill hole UE-25p#1) to more than 3,500 m beneath the northern portion of Yucca Mountain (U.S. Geological Survey, 1984).

Table II lists the major Cenozoic strata found at Yucca Mountain. The formations contain several members that are differentiated based upon lithological, physical, or chemical properties. The volcanic members are laterally continuous and range in thickness from approximately 70 to 370 m (U.S. Department of Energy, 1988).

The densely welded section of the Topopah Spring Member of the middle Miocene Paintbrush Tuff is being considered for the repository horizon. The Topopah Spring Member consists of 1) lower nonwelded to moderately welded zone, 13-42 m thick, 2) a basal vitrophyre zone, 10-25 m thick, 3) a lower nonlithophysal zone, 27-56 m thick (the probable host rock for the proposed repository), 4) a lower lithophysal zone, 43-117 m thick, 5) a middle nonlithophysal zone, 20-50 m thick, 6) an upper lithophysal zone, 54-96 m thick, and 7) a caprock zone, 39-62 m thick (U.S. Department of Energy 1988). The Topopah Spring Member is compositionally zoned, ranging from crystal-poor rhyolite at the base to a crystal-rich latite at the top (Lipman et al., 1966; Schuraytz et al., 1986).

The faults that are known to occur in the repository block have relatively minor amounts of displacement. The largest of these faults, the Ghost Dance fault, is located about 1.2 km east of our location. The Ghost Dance fault is about 3 km long and is an element of the north-trending, anastomosing set of faults found in the Yucca Mountain area. The fault dips very steeply (80 to 90°) westward and the western side is down-dropped. Displacement in the Miocene tuffs is 38 m at the south end of the repository block and decreases to an unmeasurable amount toward the north end of the block. Recognized offset on all other faults in the repository block is less than 5 m (U.S. Department of Energy, 1988).

Return to bus. Turn around and retrace route to turn off for NNWSI drill hole G-3, i.e. mileage 49.1.

69.1 Turn left on main paved road at sign "Underground Storage, Waste (USW) drill-hole USW G-4".

70.1 North end of Fran Ridge to left. Alice Ridge to north. Entering Midway Valley. Surface facility for repository will be sited in Midway Valley.

74.8 <u>Stop 2-5 Exploratory Shaft</u>

The Exploratory Shaft Facility (ESF) is a statutory requirement of the Nuclear Waste Policy Act (NWPA) of 1982, as amended 12/87. It was conceived by the architects of the NWPA as a necessary part of site characterization, because of intrinsic limitations of surface-based testing from drill holes. As presently planned the Yucca Mountain ESF will consist of two shafts connected by workings at the proposed repository level, about 320 m (1050) ft deep. Each shaft will be mined using drill-blast-muck methods, and lined with approximately 0.13 m (1 ft) of nonreinforced concrete. The shaft collars will be located approximately 218 m (715 ft) N50°E (ES-1) of USW G-4 and ES-2 91 m (300 ft) N75°E of ES-1, both on the north side of Coyote Wash near the mouth of the canyon. In this way the shaft collars will be above the calculated crest of probable maximum flood for the location. The two-shaft plan allows for extensive scientific work in ES-1, concurrent with expedited penetration and development of the main test level using ES-2.

Turn around and retrace route to Trench 14 turnoff.

78.0 Trench 14 turn left.

78.5 Turn right on jeep trail.

78.6 <u>Stop 2-7 Trench 14 and Surface Facility</u>

Deposits of calcite, opaline silica, and with or without clay and/or sepiolite occur along several faults in the vicinity of Yucca Mountain. Trench 14, where you are presently standing, is located between Exile Hill and the eastern flank of Yucca Mountain, perpendicular to the Bow Ridge fault. The trench crosses the largest and most extensive of these deposits discovered in the area to date. These deposits were discovered as a result of trench excavations across known faults during tectonic studies to detect and assess Quaternary fault movement in the vicinity of Yucca Mountain (Vaniman et al., 1988). Mapping of the trench walls began in the early 1980s. The initial interpretation of these deposits suggested near-surface accumulations in soil and rock from infiltrating meteoric water.

Current hypotheses for the origin of these deposits include upward, downward, and lateral migration of either hot (>30° C) or cold (<30° C) water under a variety of driving forces, including pedogenesis, springs, hydrothermal emplacement, and seismic pumping.

In Trench 14 (main trench) the upthrown portion of the fault consists of the Tiva Canyon Member and the downthrown side alluvial deposits. In Trench 14b the upthrown side (east) of the fault is the Tiva Canyon Member and the downthrown side a tuff unit which may be either the Tiva Canyon Member or Rainier Mesa Member (Vaniman and Levy, pers. comm.) Along the fault zone both trenches contain angular blocks of Tiva Canyon tuff, derived from a higher stratigraphic position in the Tiva Canyon Member. Trenches 14c and 14d have alluvium on either side of the fault zone.

Abundant calcite, opaline silica, and sepiolite are found along the fault in veins and also in the soils at Trench 14. Calcite and opal with or without sepiolite is a common mineral assemblage in pedogenic accumulations. These vein deposits consist of many small depositional layers or bands, some of which are cross cutting (Vaniman et al., 1988). The banded nature of the deposits indicates that the depositional mechanism was repetitive and persisted over a long time span.

Relatively fresh basaltic ash fills some fractures at the centers of vertical calcite and opaline-silica veins, crosscutting other laminae in these veins (Voegele, S.A.I.C. private comm.). The ash itself is undated but believed correlative with similar ashes in Crater Flat with ages of 1.2 and 0.27 Ma. (Taylor and Huckins, 1986).

From Trench 14 walk up the small rise to the east to the top of Exile Hill. The small valley in front of you is Midway Valley. The central surface facilities will include areas for receiving and repackaging waste shipments, site operations, and general logistical support. These facilities will occupy approximately 75 acres directly to the east of Exile Hill on an area of gently sloping alluvial fans. The surface facilities will likely be operational for 50 yr or longer. Geologic siting criteria which led to the selection of this site include the surface slope, protection from flash flooding, location of structural features such as major faults, and proximity to rock outcrops which might be used for the waste emplacement ramp portal. Additional siting criteria included the availability of a sufficiently large contiguous area, the length and inclination of the waste emplacement ramp to the centroid of the subsurface facilities, and the protection of faunal and botanical species as well as preservation of archaeological remains.

Return via Jackass Flats road to Mercury, NV.

157.3 Turn right at NRDA camp facilities.

158.7 Proceed through intersection; Bare Reactor Experiment-Nevada (BREN) Tower (height 480 m) at 10:00.

162.7 At the divide, Skull Mountain is separated from Little Skull Mountain to southwest by northeast-striking high-angle fault system, down to the northwest. There is also probably a strong left-lateral strike-slip component

163.6 Light-colored massive tuff at 3:00 is nonwelded Bullfrog Member of the Crater Flat Tuff.

164.7 Specter Range at 12:00 is composed of lower Paleozoic carbonate rocks.

166.6 Road crosses southeast-facing eroded fault scarp in alluvium; fault is part of Rock Valley system of northeast-striking Quaternary faults. About 5 km to the northeast two trenches were dug across one of the most prominent Quaternary strands of the Rock Valley fault system. This fault system is the major northeast-striking, seismically active, structural zone in the southeastern NTS area. Trench RV-2 is cut mainly in Q2 alluvium, whose age is generally between about 35,000 and 750,000 yr B.P. (Hoover and others, 1981, Yount et al., 1987). At least two faulting events appear to be recorded on the fault zone exposed in trench RV-2. It is suggested that the older event occurred after about 300,000 yr ago. The younger event can only be dated as less than about 35,000 yr B.P.

183.6 Junction of Jackass Flats road and road to Camp Desert Rock Airport.

188.0 Arrive Mercury. Dinner, then return to Beatty.

END DAY 2

Third Day Beatty, NV to Mercury, NV to Las Vegas, NV

mileage (cumulative)

0.0 Leave Beatty and proceed east on U.S. 95. Trip log same as day 2 until arrival at Amargosa Valley.

47.2 Town of Amargosa Valley, junction with Nevada State Route 29 (mileage check).

50.8 Lathrop Wells Paleozoic section (Sargent, et al., 1970), in Striped Hills, at 9:00 to 10:00, begins in Wood Canyon Formation just above the sand fan. Essentially complete Cambrian section is vertical to slightly overturned. In ascending order to north - Wood Canyon Formation, Zabriskie Quartzite, Carrara, Bonanza King, and Nopah Formations. The Bishop ash bed occurs in sandy alluvium forming large fan on south slope of hills at 9:00. The materials in the Bishop ash bed erupted from Long Valley caldera, approximately 235 km to the northwest about 730,000 yr ago. Hills at 3:00 are underlain by Bonanza King Formation.

51.3 Fresh water limestone beds in low hills on right and left. Equivalent beds have been dated at 29.3 ± 0.9 Ma. in Frenchman Flat area.

52.3 Rock Valley Wash.

53.5 Exposure of Bonanza King Formation on right.

54.8 Outcrops of Bonanza King Formation to left.

55.0 Low hills of Stirling Quartzite to right and left of highway. At 11:00 low hills of Carrara and Wood Canyon Formations.

59.0 Exposure of Ely Springs Dolomite at 8:30-9:30 (dark band), underlain by Eureka Quartzite just above valley fill and overlain by undifferentiated Silurian dolomite. Amargosa Desert is to the right.

59.5 Low pass with Silurian Lone Mountain Dolomite on left and Nopah Formation on right.

63.5 Light-gray hills at 9:00 are highly faulted Antelope Valley Limestone.

64.5 Intersection of U.S. 95 and road to Pahrump. On skyline at 1:00 are the Spring Mountains.

65.2 On right, Miocene and Pliocene gravels contain at their base ash-fall tuff layers correlative with those at the base of the middle Miocene Paintbrush Tuff (Table II), whose source is the Timber Mountain Caldera, 56 km to the northwest.

65.8 On left, contact between Late Proterozoic Stirling Quartzite and Wood Canyon Formation.

66.8 On left, large fault brings Cambrian Bonanza King Formation down against late Proterozoic and Lower Cambrian Wood Canyon Formation.

67.7 Telephone relay station on left. Bonanza King Formation at 9:00, Nopah Formation at 3:00.

68.0 Left side of road is southeast end of the Specter Range; right side is northwest end of Spring Mountains. Rocks in canyon alongside highway are largely Bonanza King Formation of Cambrian age.

71.2 Army #2 well site on left.

73.5 Mercury interchange. (Mercury camp 4:00). Turn right off divided highway and go to Mercury.

77.5 Gate to Mercury, NV. Badge Office to right.

78.5 <u>Stop 3-1 U.S. Geological Survey Core Library</u>

The Geologic Data Center and Core Library, maintained by the USGS at the NTS, is a depository for systematic processing, cataloguing, and storage of drill hole and other rock samples from the NTS and other test areas. The facility maintains reference files of reports, maps, aerial photographs, downhole video tapes of selected drill holes, geophysical logs for NTS and other test areas. Handling of water samples for both chemical and radiological analyses is expedited in a hydrologic-chemical laboratory. The facility serves as field headquarters for USGS geologists, hydrologists, and geophysicists and serves as a work area for earth scientists in support of weapons testing and waste-management projects of the Department of Energy (DOE).

The Data Center complex comprises the three cojoined buildings at Stop 3-1 and three other buildings. To date, storage has been provided for about 760,000 m of drill-hole samples stored in about 50,000 boxes. Drill-hole samples include drill-bit cuttings, nominally collected each 3 m of drilled interval, borehole sidewall samples, percussion-gun borehole sidewall samples, and conventional diamond-bit core samples. Detailed records, comprising thousands of data cards, are maintained on all samples, including date received at the library, source, and final storage or disposition.

Leave Mercury heading north on Mercury Highway from housing area. View of Red Mountain-Mercury Ridge geology (Barnes and others, 1982). Red Mountain, between 9:00 and 12:30, is composed of gray and brown Ordovician Antelope Valley Limestone through Eureka Quartzite on left, Ely Springs Dolomite and Silurian dolomite on right. Strata on Red Mountain generally dip eastward. Mercury Ridge, between 1:00 and 2:00, is composed mainly of Devonian Nevada Formation and Devils Gate Limestone. North Ridge, between 2:00 and 3:00, is composed of Middle and Upper Cambrian carbonate rocks thrust over Devonian and Mississippian rocks (Spotted Range thrust) in the axial portion of the Spotted Range syncline. South Ridge, between 2:30 and 4:00, consists of Ordovician through Mississippian rocks that form the southeast limb of the Spotted Range syncline. Tower Hills, at 4:00, are Devils Gate Limestone. Specter Range in distance, between 7:00 and 9:00, contains Cambrian through Devonian rocks, and a major thrust fault (Specter Range thrust) that brings Upper Cambrian and Ordovician rocks over middle and upper Paleozoic rocks (Sargent and Stewart, 1971). The Spotted Range thrust to southeast and the Specter Range thrust may be parts of a single major thrust system (CP thrust) in the NTS area. Northeast-trending topography is controlled by N 45°-60° E trending Tertiary left-lateral strike-slip faults of the Spotted Range-Mine Mountain structural zone.

80.3 Checkpoint Pass, Gate 200.

81.2 Old Mercury Highway Junction to left (mileage check).

Stop 3-2: Over view of Frenchman Flat Geology. At Pump Station No. 4.

Facing north and looking counterclockwise: Range Mountains at 2:00 are composed of southeast-dipping Paleozoic rocks from carbonate rocks of the Ordovician Pogonip Group through Devonian Nevada Formation. Older Tertiary gravels form low hills in foreground. To north-northeast is Frenchman Lake playa and beyond is Nye Canyon, containing several basalt centers dated between 6.0 and 7.0 Ma. (R. F. Marvin, USGS, written commun., 1980, in Dockery et al., 1985). High peak on skyline is Bald Mountain in the Groom Range 80 km to north-northeast. French Peak and Massachusetts Mountain at 12:00 on the northwest side of Frenchman Flat consist primarily of faulted Paintbrush and Timber Mountain Tuffs. Flat-topped mountain on distant skyline at 11:30 is Oak Spring Butte at north end of Yucca Flat.

At northwest corner of Frenchman Flat are CP Pass and CP Hogback (named after Control Point Headquarters). To left of CP Pass are the CP Hills composed of Cambrian rocks and Mississippian rocks overlain by Tertiary volcanic rocks. High skyline in far distance at 11:00 is Rainier Mesa. Directly to the left of Rainier Mesa on the skyline is Tippipah Point. At 10:00 on skyline is Shoshone Mountain, which forms part of the southeast rim of Timber Mountain caldera. In the intermediate foreground at 10:00 are the intermediate lavas of the Wahmonie-Salyer volcanic center on the northeast end of Skull Mountain. Hample Hill at 9:30 in intermediate distance is capped by the Ammonia Tanks Member of the Timber Mountain Tuff, which is underlain by eolian sandstone.

At 10:00 and 2:00 in the near distance (1.6 to 3 km) 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 at 7:00 to 8:00 where they onlap or are faulted against the Paleozoic rocks. The Horse Spring Formation contains a tuff bed dated at 29.3 Ma. (Marvin and others, 1970), which is probably air-fall tuff of the Needles Range Formation of eastern Nevada (Barnes et al., 1982).

The valley is underlain by playa

deposits and alluvium, probably 1,525 m (5,000 feet) deep in the center of the basin. Tertiary volcanic deposits are thick in the northern part of the valley, which marked the edge of the Tertiary volcanic basin, and are virtually absent on the south side.

Water supply for Mercury is obtained from Army Well 1 located on U.S. Highway 95 east of the junction to Jackass Flats, and from wells 5A, 5B, and 5C at Frenchman Flat. Water from Army Well 1 is pumped from Paleozoic carbonate aquifers; water from the wells in Frenchman Flat is obtained from valley fill and volcanic rocks. Water from wells in Frenchman Flat is of the sodium potassium bicarbonate type; calcium magnesium bicarbonate water is obtained from the Paleozoic carbonate aquifers in Army Well 1. Several air-burst tests were conducted in Frenchman Flat prior to the moratorium on nuclear testing in 1958. The north end of the valley has been developed as a test area for underground explosions since that time, but is not currently used. Return south along Mercury Highway 0.5 mile.

82.5 Junction Old Mercury Highway, hard right turn onto old road.

83.3 White hills at 10:30 are underlain by Eureka Quartzite. Along sky line at 10:00 Eureka Quartzite underlain by Antelope Valley Limestone and overlain by Ely Springs Dolomite can be seen.

84.2 Low hill at 9:00 is composed of Horse Spring Formation of Oligocene age; and is the oldest Tertiary formation on the NTS. At 3:00 hills of younger Oligocene and Miocene rocks of Pavit Springs.

84.8 <u>Stop 3-3 Southwest Frenchman Flat Detachment</u>

Dirt road to left, on curve. Bus will remain on road, with smaller vehicles drive off road and make turn back to south. Follow jeep trail. Walk or drive south approximately 1/2-3/4 mi. Cross wash to west.

"Structural relationships interpreted from detailed USGS geologic maps of the Nevada Test Site area suggest that Tertiary strata are tectonically detached from their Paleozoic substrate. Mapping of about 5 km^2 of the hill country along the southwest margin of Frenchman Flat revealed exposures of a low-angle tectonic contact between a massive, undulating pavement of Ordovician limestone and overlying strongly fractured Tertiary strata. The Tertiary rocks are conformable to moderately inclined to the smooth, unstriated floor. The resistant Ordovician section dips gently eastward, is not folded, but is broken by easterly and northeasterly trending high angle faults. The overlying Tertiary section, originally mapped as the Horse Spring Formation of Oligocene age, is composed of incompetent siltstone and claystone, minor lacustrine limestone beds, and a distinctive conglomerate bed. These marker beds demonstrate that the Tertiary strata are strongly folded and locally overturned. The fold geometry largely reflects the shape of the Paleozoic floor, which is partly paleotopographic and partly due to high-angle faulting, and implies that the Tertiary blanket was folded as it was detached and transported over the irregular surface. These events post-date regional volcanic activity as young as 11.5 MA. The high-angle faults were probably active at the same time that the Tertiary strata were moving across the Paleozoic floor because the Tertiary blanket generally is not cut by these faults. The extent of the detachment, its movement direction, and the magnitude of lateral transport have yet to be defined. Preliminary mapping at the north end of Yucca Flat, 60 km to the north, suggests similar relationships between a floor of Paleozoic sedimentary rocks intruded by Cretaceous granite and the overlying 16 Ma tuffs. Detachment of the Tertiary strata apparently is not a local phenomenon related to oroclinal bending at the northwest end of the Las Vegas shear zone." (From Myers, 1986). Return to bus. Lunch. Proceed north. From Stop 3-3 road passes through low hills composed of rocks of Pavit Spring.

87.5 Junction with new Mercury Highway, turn left.

92.8 Turn right onto 5-07 road.

93.5 At 9:00 dark re-entrant is vitrophyre lava of the Wahmonie

Formation onlapped by Topopah Spring Member of the Paintbrush Tuff.

95.0 Turn right onto gravel road.

95.3 Stop 3-4 Radionuclide Migration (RNM) project site

The RNM project was initiated in 1974 to study rates of the underground migration of radionuclides from explosion-modified zones at NTS. The Cambric event, detonated in Frenchman Flat in 1965, was chosen for the study for several reasons. The Cambric explosion cavity is within the NTS Area 5 water-supply aquifer, where leakage could have contaminated the water supply. Hydrologic modeling indicated that sufficient time had elapsed for ground water to fill the cavity and chimney to the preshot static water level, which is 73 m above the detonation point. The Cambric detonation point is only 294 m below ground surface, and thus the re-entry drilling and sampling operations were less difficult and expensive than for more deeply buried tests. The site is also far enough from the areas of active nuclear testing so that damage or interruption of the re-entry and sampling operations from those activities would be unlikely. Sufficient tritium (^3H or T) was present to provide an easily measurable tracer for water from the cavity region. The postshot debris and ground water in the cavity and chimney also contained enough plutonium, uranium, and fission products so that they could be measured and compared. The small nuclear yield from the Cambric event was expected to have little effect on the local hydrology. Further, the alluvium also constituted a good medium for hydrologic studies because it is more permeable than tuff and does not have large fissures or cracks through which the water might selectively flow.

The Cambric field studies began when the Cambric cavity region was re-entered in 1974, and samples were taken to determine the radionuclide distribution between the solid material and water. Beginning in October 1975, water was pumped from a satellite well located 91 m from the Cambric cavity; this induced a sufficient artificial gradient to draw water from the Cambric cavity and provide an opportunity to study radionuclide transport under field conditions.

The RNM-2S satellite well has been pumped nearly continuously since 1975 at the rate of about 600 gal/min. Samples are analyzed weekly for tritium. In the summer of 1978, tritium was first detected and reached a peak of 700 pCi/ml by late summer of 1980, when the concentration of tritium began to decrease. By September 30, 1982, over 42% of the tritium from Cambric had been removed by the satellite well. These tests significantly enhance our understanding of the ground-water transport of radionuclides from nuclear explosion cavities in general (Daniels, 1983).

At 8:00-10:00 east-northeast-trending Quaternary fault scarps may be visible in fans at the base of the Ranger Mountains. Return to paved road, turn right (east).

95.5 Turn right onto 5-01 road.

98.0 Y in road. At 3:00 man made structures on playa were tested by nuclear blasts.

101.0 Gravel pits to left provide material used in the backfilling of drill holes used for nuclear tests. Thickest alluvium (1220 m) in Frenchman Flat, as determined by gravity, is approximately 3 km northwest of Frenchman Lake, near Stop 3-3.

102.0 To right, look along Rock Valley where Quaternary fault scarps have been recognized. Fault zone crosses road at approximately this point and continues northeast to foot of Ranger Mountains.

103.5 At junction of Mercury Highway proceed south toward Mercury.

109.0 Gate 100. Leaving NTS. North end of Spring Mountains is at 10:00-12:00. Low rounded hills across U.S. 95 are Precambrian-Cambrian quartzites. Specter Range, containing Paleozoic carbonate rocks is at 12:00-3:30. Complexly deformed Spotted Range is at 9:00.

Mercury Valley to southeast is the northernmost topographic expression of the northwest-trending Las Vegas Valley or La Madre shear zone. Northeast-striking structures, including thrusts in the Specter Range (Sargent and Stewart,

1971) and Spotted Range, can be correlated across Mercury Valley with little or no offset. No significant northwest-striking faulting is present in Pliocene and Pleistocene deposits of Mercury Valley.

112.7 Junction with U.S. 95, turn left toward Las Vegas.

Massive gray cliffs at 9:00 are the Palliseria-bearing limestone in the middle part of the Ordovician Antelope Valley Limestone (lower part of the Aysees Member of the Antelope Valley Limestone in the Ranger Mountains). Underneath are brown slopes of the Orthidiella-bearing silty limestone (Ranger Mountains Member of the Antelope Valley Limestone in the Ranger Mountains).

113.3 Low ridges between 8:30 and 10:30 are Ordovician Antelope Valley Limestone. Ridge on skyline between 11:00 and 1:00 consists of Eureka Quartzite through Devils Gate Limestone.

116.9 Stop 3-5 Spotted Range Geology (optional)

View of Paleozoic units in the Spotted Range between 6:00 and 10:00. Park off highway on right side near sign designating Nye-Clark County line. Rocks seen to the north in the Spotted Range are typical thick miogeoclinal strata similar to those in the Lathrop Wells section. Visible units include limestone of the Ordovician Pogonip Group, Eureka Quartzite, and Ely Springs Dolomite (see Table I); Silurian and Lower Devonian dolomite; Lower and Middle Devonian dolomite and quartzite of the Nevada Formation of former usage, and Middle and Upper Devonian Devils Gate Limestone (includes some dolomite and quartzite). Uppermost Devonian and Lower and Upper Mississippian rocks cannot be seen from here, but are present in an overturned syncline on the far side of the ridge on the skyline. Strata seen generally dip 30° to 40° northwestward and form the southeast limb of the Spotted Range syncline. The rocks are displaced by a prominent system of northeast-trending faults. White quartzite member of the Eureka just above valley fill at 7:30 is overlain by black dolomite of the lower member of the Ely Springs. Ridge on skyline between 6:30 and 8:30 is South Ridge capped by Devils Gate Limestone. Nevada-Devils Gate contact is on skyline at 7:30. Prominent black band with brownish slope-former below is the lower part of the Nevada Formation and can best be seen in middle part of range between 8:00 and 8:30.

119.3 Brown and gray outcrops immediately north of highway are Pogonip Group.

122.5 Road to right leads to test well 4 - continue straight ahead. Lake beds of the Las Vegas Formation form the yellowish-gray badland topography along highway. These beds, marking a significant shoreline of a large lake, continue westward only a few more miles where they reach a maximum altitude of about 1100 m. They are continuous from that point back to an altitude of about 800 m in the Las Vegas area, suggesting a southeasterly tilting during the last one million years of approximately 5 m/km.

124.3 Prominent ridge on skyline between 3:00 and 6:00 is northwest end of Spring Mountains; Wheeler Peak at 3:30, Mount Stirling at 4:30.

126.6 Village of Cactus Springs. Prominent black and white banded dolomite on ridge between 7:00 and 9:00 is upper part of Nopah Formation.

129.9 Village of Indian Springs. Indian Springs Valley is at 9:00. White and brown outcrops in distance at 7:00 are Eureka Quartzite. Gray and brown outcrops forming prominent ridge south of town, 3:00 to 5:00, are Bird Spring Formation.

131.0 Light-gray outcrop, at 9:00, is mostly Devonian carbonate rocks. Near this point, the trend of Las Vegas Valley changes from east-southeast to southeast past Indian Springs, reflecting either a bend in the Las Vegas Valley shear zone or the presence of a conjugate northeast-trending fault.

133.0 Southwest end of Pintwater Range between 7:00 and 9:00 is composed of Ordovician, Silurian, and Devonian rocks. Ridge at 4:00 consists of gray cliffs of Monte Cristo Limestone and alternating brown silty-sandy limestone and gray limestone of the Bird Spring Formation.

137.1 State Correctional Facility, Camp Bonanza (Boy Scouts of America), and Cold Creek Road on left. Continue straight ahead.

139.0 One of the Playa of Three Lakes Valley at 8:00. Indian Ridge at 4:30 is composed of Cambrian and Ordovician rocks. Ridge between 2:00 and 4:00 is composed of Bird Spring Formation. The Wheeler Pass thrust probably separates these two ridges.

142.5 Lee Canyon turnoff. Pull onto Nevada 52 to right.

142.6 Stop 3-6 Las Vegas Shear Zone and Sheep Range Geology

The Las Vegas Valley is coincident with the Las Vegas shear zone. A major northwest-trending feature, the shear zone separates the relatively unextended Spring Mountain block from the extended terrain to the northeast that includes from southeast to northwest the Las Vegas Range, Sheep Range, Desert Range and Spotted Range. The offset of Gass Peak thrust, at the base of the Las Vegas Range and the Wheeler Pass thrust to the northwest of this stop is cited as evidence for right lateral displacement along the zone. The contrast in sedimentary facies and stratigraphic thickness on opposite sides of valley offers corroborative evidence of lateral movement.

To the northeast the rocks of the Sheep Range are the typical thick miogeoclinal section of eastern Nevada. The two prominent black bands at 3:00 are the lower member of the Ely Springs Dolomite repeated by faulting. Beneath the upper of the two black bands is the light-colored Eureka Quartzite. The Eureka is underlain by brownish-gray carbonate rocks of the Pogonip Group, which in turn are underlain by the Nopah Formation, the uppermost part of which has prominent black and white stripes. Above the black lower member of the Ely Springs is a unit of light-gray dolomite representing the upper member of the Ely Springs and lower part of the Silurian section. The thin black band is a dark dolomite unit within the Silurian section. The Devonian rocks above are similar to the Nevada Formation of former usage and the Devils Gate Limestone of the NTS.

The Sheep Range detachment (Wernicke et al., 1984) has resulted in the eastward rotation of the Sheep Range. Along the west side of the Sheep Range is the Hoodoo Hills havoc (Guth et al., 1988). These hills consist of complexly deformed Paleozoic rocks. Black Basin along the west side of the Hoodoo Hills was formed by extensional deformation in the Miocene (Guth et al., 1988). Guth et al. (1988) interpreted the Hoodoo Hills havoc as a series of fault slivers along a major extensional fault and a series of gravity slides into the Black Hills Basin as it was developing.

The Lee Canyon thrust, a smaller thrust, between the major Keystone and Wheeler Pass thrusts, goes up Lee Canyon to the west.

146.0 Badland topography at 9:00 developed on Las Vegas Formation. Near Las Vegas, similar yellowish-gray fine-grained beds have yielded fossil mollusks and mammals of Pleistocene age.

147.7 Lucky Strike Canyon Road to right. Road to left leads to Corn Creek Springs Field Station of U.S. Fish and Wildlife Service, which manages the Desert Wildlife Game Range. The ridge east of Lucky Strike Canyon consists of a much thinner section than in the Sheep Range and contains several different lithofacies. At 4:00 a white streak representing the distal end of the Eureka Quartzite may be seen just below a prominent black unit, which is probably equivalent to the Ironside Member of the Sultan Limestone. A thin light-gray dolomite separates the Eureka and Ironside. This dolomite interval consists of the Ordovician Ely Springs Dolomite and possibly a thin sequence of Silurian rocks. The Devils Gate Limestone forms the remainder of the ridge above the black Ironside. The Mississippian Monte Cristo Limestone forms the north-dipping slope of the main ridge and cannot be seen from here. The well-bedded outcrops at 5:00, north of Lucky Strike Canyon, are the Pennsylvanian and Permian Bird Spring Formation. Below the Eureka, at Lucky Strike Canyon, the section is gray and brown silty and clayey carbonate rocks of the Pogonip Group. The black dolomite just above the valley fill at 3:30 is the upper part of the Nopah Formation.

Fossil Ridge at 10:00 is composed of Cambrian and Ordovician rocks. Gass Peak thrust (Fig. 1) at 8:30 separates upper plate of Cambrian rocks on left from lower plate of Pennsylvanian and Permian rocks of the Las Vegas Range on the right.

155.9 Charleston Park Road - Kyle Canyon turnoff (Nevada State Highway 39). The Kyle Canyon alluvial fan is one of the largest fans on the east side of the Spring Mountains. It was built by ephemeral streams, principally Kyle Canyon Wash. Four geomorphic surfaces, with soil development features indicate the development of the fan was episodic (Sowers et al., 1988).

157.2 View of La Madre Mountain stratigraphy between 3:00 and 4:00. Lower thin black band is dolomite of Devonian age (probably Ironside Member of Sultan Limestone). It rests with apparent unconformity on a very thin gray dolomite of Devonian or possibly Silurian age, which in turn rests unconformably on gray and brown silty and clayey carbonate rocks of the Pogonip Group of Ordovician age. Above the Ironside is limestone and dolomite of the Devonian Sultan Limestone. The main ridge is capped by Monte Cristo Limestone of Mississippian age. Small outlier just north of the end of the main ridge is composed of the Bird Spring Formation of Pennsylvanian and Permian age.

162.9 Craig Road turnoff. Potosi Mountain at 2:30 is capped by Monte Cristo Limestone of Mississippian age. Prominent ridge between 2:00 and 3:00 is capped by Permian Kaibab Limestone. Wilson Cliffs between 2:30 and 3:30, composed of buff and red Aztec Sandstone of Triassic(?) and Jurassic age, form the lower plate overridden by Wilson Cliffs thrust. Narrow ridge at 3:30 is an erosional remnant of Keystone thrust; the ridge is capped by gray Goodsprings Dolomite of Cambrian and Ordovician age overlying red Aztec Sandstone. On La Madre Mountain between 3:30 and 5:00 are exposed carbonate rocks of Cambrian, Ordovician, Silurian(?), Devonian, Mississippian, Pennsylvanian, and Permian age. On Las Vegas Range between 7:00 and 9:00 most outcrops are the Bird Spring Formation of Pennsylvanian and Permian age. Muddy Mountains at 8:00. Sunrise and Frenchman Mountains between 10:30 and 11:30.

169.3 Decatur Blvd. overpass.

172.0 Las Vegas, intersection of Interstate 15 and U.S. 95. Proceed south on U.S. I-15.

176.9 Junction I-15 and Tropicana Avenue.

END OF DAY 3.

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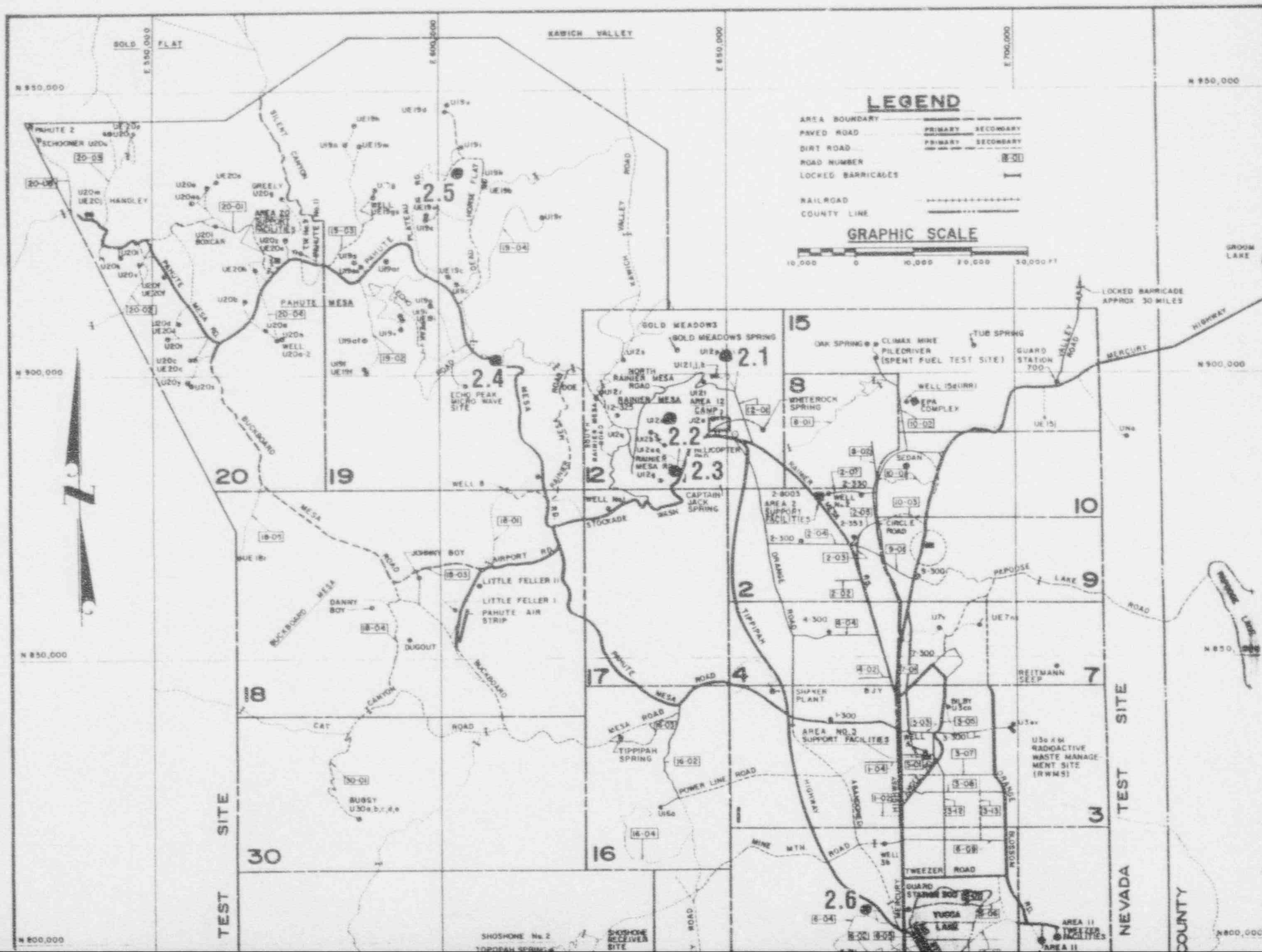
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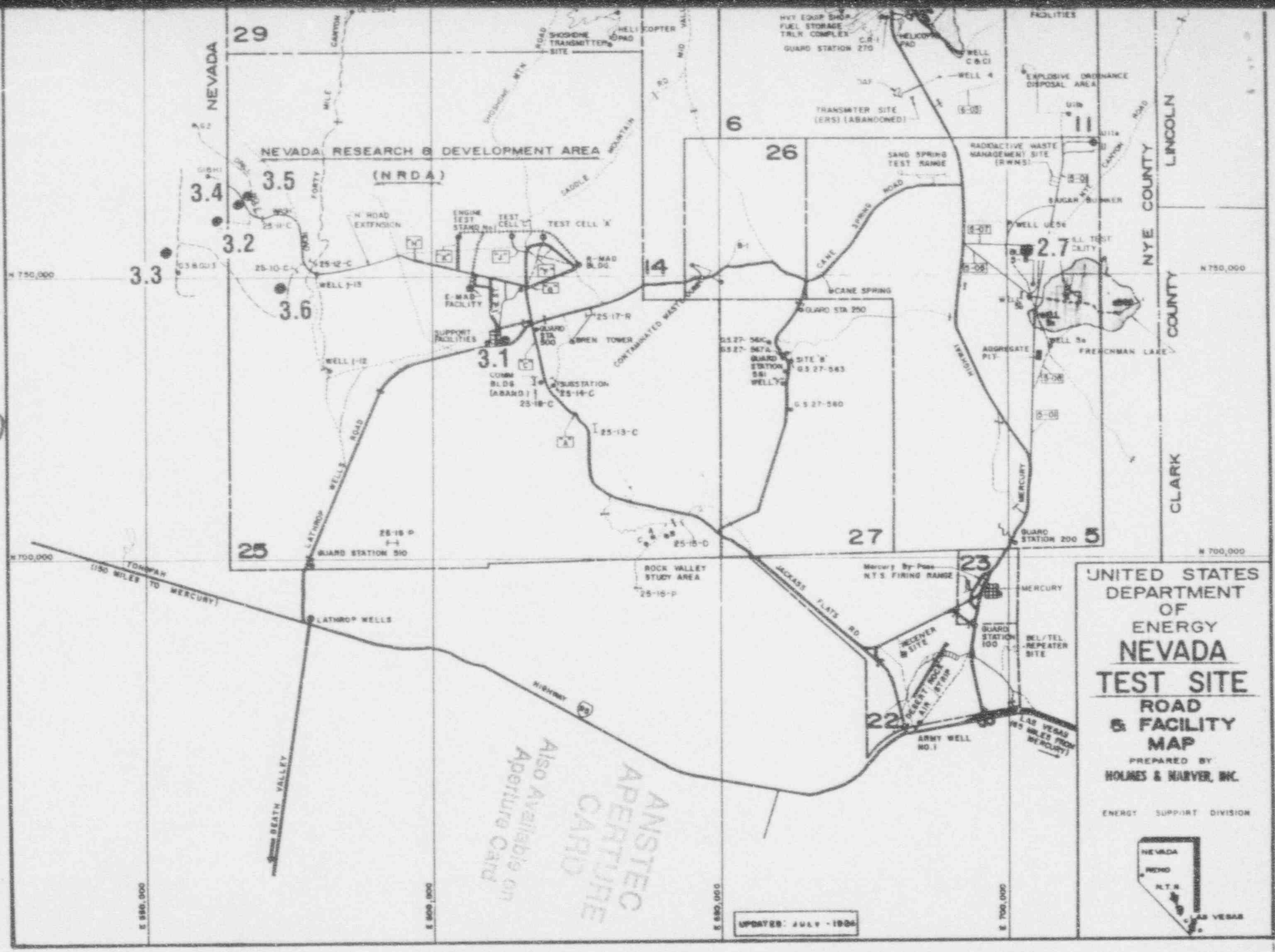

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