Overview of the Potential Nuclear Waste Disposal Site at Yucca Mountain, Nevada

Carmen Caceres Department of Geological Sciences, California State University

Northridge, 91330

The Department of Energy's (DOE) Civilian Radioactive Waste Management (OCRWM) has been conducting studies since the early 80's to determine if Yucca Mountain is a suitable site for a nuclear repository. Yucca Mountain is located on the south eastern edge of the Nevada Nuclear Test Site (Figure 1.). It was formed by several eruptions of a composite volcano that created a caldera. The caldera was filled with four major layers of ash-flow tuff and minor ash-fall layers from eruptions of nearby volcanoes. These layers alternate and form relatively non porous to highly porous rock. These events occurred 12 million to 15 million years ago (Miocene) and produced more than 1,000 cubic kilometers of silicic magma (DOE). The alternating layers of tuff make up the Paintbrush Tuff Formation. Within this formation is the Topopah Spring Member that is located about 300+ meters below the surface of Yucca Mountain (Figure 2.). It is the thickest, typically about 100 meters throughout the member, most extensive member of the Paintbrush Formation and consists of densely welded tuff. Studies are being conducted to determine if this layer will be suitable to host the repository.

Today the composite volcano that formed Yucca Mountain is extinct. Yucca Mountain now has a system of predominantly northerly-striking normal faults that dip westward (Carr and Yount, 1988). These faults were displaced approximately 11.5-12.5 m.y. ago (Carr and Yount, 1988) and today are being studied to determine the possible influence that they may have on the repository.

WHY WAS YUCCA MOUNTAIN CHOSEN?

In 1982 Congress established the Nuclear Waste Policy Act to solve the increasing problem of high-level nuclear waste. One year later nine locations in six states were chosen as potential sites of nuclear repositories. Congress amended the Act in 1987 and ordered the DOE to study only Yucca Mountain as a possible site.

Yucca Mountain has a number of natural and political characteristics that make it an attractive site for a nuclear repository. One of the natural aspects that make it a prime candidate for the repository is that there is very low precipitation in the area, about 15 cm/yr, most of which runs off or evaporates (Keller, E., 1996). Low precipitation is favored in order to reduce the potential of contamination to the water table. The less water that is available to percolate through the site of the repository, the less the potential of contamination to the water table. Hydrologists have estimated that less than 5 percent of the precipitation infiltrates the surface and eventually reaches the water table (Keller, E., 1996). Another favorable condition at Yucca Mountain is a deep water table. The water table is located 244-366 meters below the level of the proposed repository site

(Pipkin, B., 1994). This condition is favorable for two reasons: 1) A water table 244-366 meters below the level of the proposed repository site means that ground water will not be flowing through possibly contaminated rocks. This reduces the chances of contaminated ground water to be carried away from the site and to possibly contaminate other areas. Rates of ground water flow are estimated at 3,400-8,300 years/mile (Pipkin, B., 1994). 2) The combination of low precipitation and a deep water table reduce the chances of rain water to percolate through the rock, pick up possible contaminates, and then carry them down to the water table.

The lithology of Yucca Mountain is another natural component that makes this site favorable for a nuclear repository. The Paintbrush Formation is composed of welded and non-welded zeolitic tuffs. This is beneficial because these rock types have a high absorption capacity for radioactive material (Keller, E., 1996). Radionuclides are radioactive particles. If for any reason these radionuclides are released from the repository, the tuff will act as a natural barrier. In theory radionuclides will be carried down by precipitation and will be attracted to zeolites and other minerals found within the tuff. These zeolites containing the radionuclides will then attach to the tuff preventing further movement of most of any contamination (Figure 3.).

The geology of Yucca Mountain was important in choosing the site for the repository, but politics also played a part in the decision. Probably one of the most significant factors is that the land for the proposed site is already under DOE control. Other factors that make this a good site is sparse population and that it is easily accessible by highway and railroads.

WHAT TYPE OF WASTE WILL BE STORED IN THE REPOSITORY?

Nuclear waste is the by-product of making electricity and from the production of weapons at defense facilities. Two types of high-level nuclear waste arise from these activities. Spent fuel assemblies is one type, and is the primary source of nuclear waste. These assemblies consist of solid pellets of enriched uranium. The pellets are sealed in tubes and are used inside a nuclear reactor to produce electricity (DOE). Once a year about one-third of the fuel inside the reactor must be replaced with fresh fuel. The spent fuel is now being stored in pools of water but a permanent storage place is necessary.

Spent fuel contains about 95-1/2 % uranium, about 1% plutonium, and 3-1/2% fission product that can still be used. The process to recover the uranium and plutonium is known as reprocessing. Although this may seem like a feasible method to "recycle" spent fuel, the by-product of reprocessing is radioactive high-level liquid waste. The cost of reprocessing has limited this method of recovering useful elements to military and defense.

The Yucca Mountain nuclear repository is being built to store both spent fuel assemblies and high-level liquid reprocessing waste. No liquids well be stored in the repository. High level liquid waste will be processed into a glass-like solid and placed into containers filled with inert gas before it is stored.

WHAT ARE SOME POSSIBLE GEOLOGIC CONCERNS?

Although today Yucca Mountain may seem like a stable and suitable location for a nuclear repository, geologic settings may change with time. One of the possible changes that may occur with time is a fluctuation in the water table. Today low precipitation and a deep water table make it safe to build the repository, but what if the water table rises? Increased rainfall could raise the level of the water table up to the repository. It is estimated by the DOE that during the last glacial maximum, precipitation in the area was 30 to 40 percent higher but raised the water table only afew tens of meters (DOE). Volcanism has also raised some concerns. The volcanoes that formed Yucca Mountain and the surrounding landscapes were silicious. This type of volcano is very explosive because of the high silica content. Studies concluded that future eruptions of these volcanoes are not a serious hazard. There has been no slilicic volcanism in the Nevada Test Site region in the past 7 Ma. and volcanic activity within the great basin has ceased in the past 10 to 20 ma (DOE). Siesmicity in the Yucca Mountain region may also pose a hazard to the repository. For this reason trenches are being excavated to study fault movement during the past two million years. Studies of local faults reveal little movement with possibly thousands of years between those movements (DOE). Experiences all over the world have also shown that underground structures can withstand the motion of an earthquake. According to DOE studies, there is strong indication that Yucca Mountain would remain stable over the period of time required.

CONCLUSION

Studies of Yucca Mountain started in 1987 and continue to this day. If the site characterization determines that Yucca Mountain is capable of isolating nuclear waste, construction will begin about 2004 (DOE). Only some of the major concerns regarding the repository were discussed here. There are several other issues that must be considered and studied to determine if and how they will effect the repository. At present time there seems to be nothing to preclude the building of a repository at Yucca Mountain but the Nuclear Regulatory Commission will decide once studies are completed if construction will begin.

REFERENCES

Carr, M.D., and Yount, J.C., 1988: Geologic and hydrologic Investigations of a Potential Nuclear Waste Disposal Site at Yucca Mountain, Southern Nevada, U.S. Geological Survey Bulletin 1790.

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Pipkin, B., 1994: Geology and the Environment, West Publishing, 437-439 p.

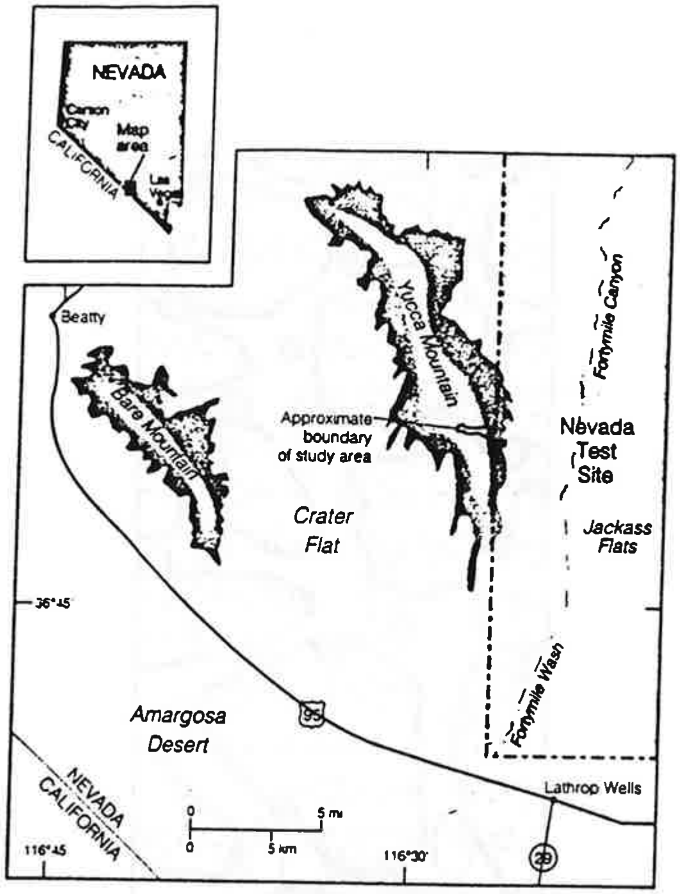

Fig.1. Location map of Yucca Mountain study area. (Pipkin, B.,1994)

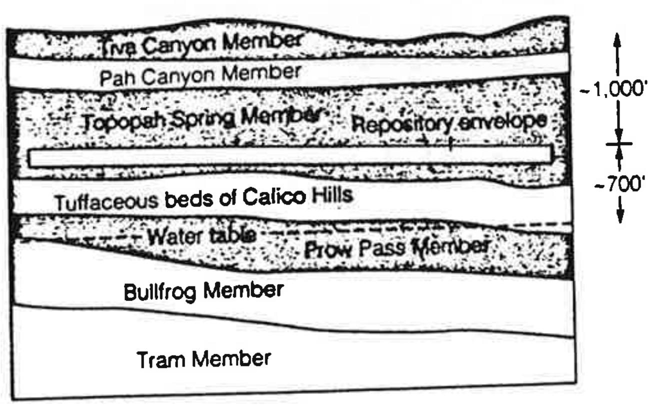

Fig. 2. Paintbrush Tuff Formation at Yucca Mountain, including the Topopah Spring Member. (Pipkin, B.,1994)

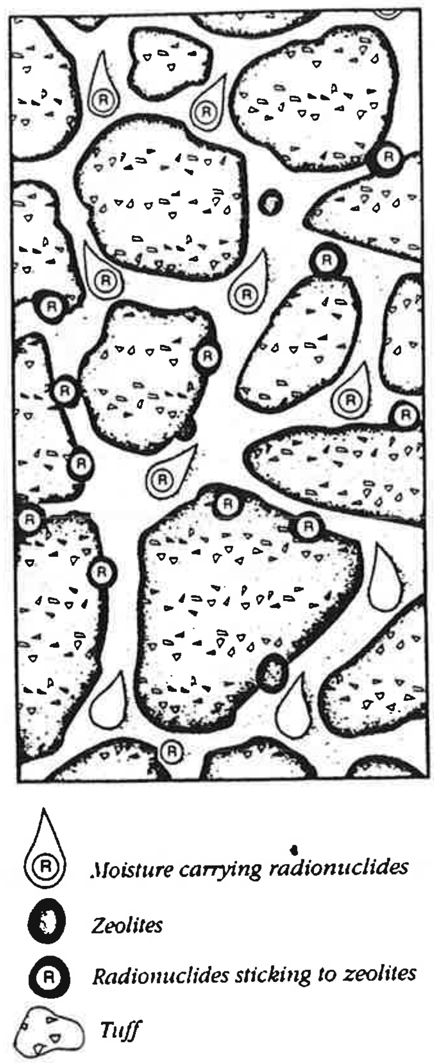

Fig. 3 Artist's concept showing the interaction of zeolites and radionuclides. In this drawing, moisture is shown moving in a cross-section of tuff. Some of the drops of moisture carry radionuclides (radioactive particles). As the radionuclides come in contact with the zeolites, they would be attracted to the zeolites, sticking to them, and, with less intensity, to the tuff. (DOE)

GEOLOGY / HYDROLOGY FIELD TRIP
YUCCA MOUNTAIN PROJECT AREA
NEVADA TEST SITE

Revised for California State University 1/25/96

Field Guide by Daniel J. Soeder, U.S. Geological Survey,
P.O Box 327, MS 743, Mercury, NV 89023 (702) 295-5996

NOTE: Most of this field trip will be on the Nevada Test Site, which is a sensitive, high security area. Do not bring binoculars, cameras or any kind of a recording device. They are a *security violation* and will be confiscated. Although we will not be going into any known radiation hazard areas, for your own protection do not collect rock samples. Don't disturb any of the wildlife, which is protected and often poisonous. The climate of this area is a high desert. Wear a hat, sunblock, sunglasses, loose clothing, and good boots. Bring a canteen and be prepared for some hiking and climbing.

8:00 AM Meet in Mercury, Nevada at the badge office. A photo identification is required to issue a Nevada Test Site badge. Keep your badge displayed on the upper part of your body at all times. Do not mutilate it, destroy it, *or lose it*! If you do, you are going to have a very difficult time leaving the Test Site at the end of the day.

8:30 AM Depart Mercury, Nevada in vans for Yucca Mountain Project facilities in Area 25. As we head out Jackass Flats Highway, the Spring Mountains will be on our left. Named for their groundwater supplies, the Spring Mountains are the surface expression of the Keystone Overthrust, a thrust sheet of Paleozoic marine carbonates and shales on top of Triassic and Jurassic marine limestones and fluvial and aeolian clastics. The thrusting was related to the Mesozoic-age Sevier orogeny (Galloway, et al., 1991). Carbonate rocks are cliff-formers in this desert environment, and usually weather to a black color. The highest peak in the Springs is Mt. Charleston at approximately 12,000 feet. The Spring Mountains decline to the northwest at Point of Rocks, and then resume for a short distance as the Specter Range. Point of Rocks is an old railroad pass and the route for modern US Highway 95.

Mercury Valley is the westernmost topographic expression of the Las Vegas Valley and La Madre shear zones (Carr, 1974). The eastern end of Mercury Valley is bounded by a major drainage divide, and there is a groundwater drainage divide here as well. Groundwater under the Test Site and Yucca Mountain flows to the south and southwest toward Death Valley, while water in the Las Vegas Valley flows southeast and east into the Colorado River. The Las Vegas Valley is formed by a northwest-oriented shear zone with an estimated right lateral strike-slip movement of 25-30 km (Dockery, et al., 1984). Movement on the shear occurred from about 17 Ma to 11 Ma, and resulted in a conspicuous westerly bending or drag on the ranges to the northeast side of the valley. Some spurs of the Spring Mountains on the southwest side of the valley show this drag in the opposite direction.

This area has classic arid land geomorphology. Look for alluvial fans, bajadas and inselbergs along the Spring Mountains and Specter Range as we drive out of Mercury. About 10 miles outside of Mercury, the road goes through some tight curves and descends into Rock Valley. The aptly-named Striped Hills on the left are comprised of Paleozoic marine sedimentary rocks with nearly vertical dips, although Skull Mountain on the right and Little Skull Mountain directly ahead are composed of gently dipping Tertiary volcanics. A nice reverse fault is visible on the south face of Little Skull Mountain.

An important, northeast trending, strike-slip fault occurs in Rock Valley. Orange tortoise fence marks the location of a trench on a strand of the Rock Valley Fault near the southern flank of Skull Mountain. This trench, and others like it, are used for paleoseismic reconstructions of Holocene and Quaternary movement on faults. The Rock Valley Fault is the most active fault in the Yucca Mountian area. A Richter magnitude 4.3 earthquake occurred on a spur of the Rock Valley Fault under Little Skull Mountain on May 28, 1992, which caused some damage to the project facilities in Jackass Flats. The focus of this earthquake was about 4 km deep and the motion was predominantly strike-slip (John Whitney, USGS, personal communication). If the weather cooperates, the Funeral Mountains and the Panamint Range will be visible to the southwest. The California state line is just in front of the Funerals, and Death Valley is between the Funerals and Panamints. On exceptionally clear days, the Sierra Nevada and Mount Whitney (elev. 14,500') can be seen to the southwest. After crossing through Skull Pass, our first stop will be a pull-off on the descent into Jackass Flats for an overview of the area.

8:50 AM <u>STOP 1</u>: (10 min) Jackass Flats is an alluvial-filled basin with exterior drainage to the south. Yucca Mountain is the long, straight ridge off to the west; Busted Butte can be seen east of it. The north end of Yucca Mountain is known as the "Prow"; north of it is Yucca Wash, followed by Pinnacles Ridge. The caldera complex that erupted these volcanics is bordered by Pinnacles Ridge. East of Pinnacles Ridge are the colorful Calico Hills, composed of hydrothermally-altered volcanic tuffs and rhyolite flows. The tallest feature east of Calico Hills is Shoshone Mountain, which was centered on a vent and consists primarily of rhyolite. Features to the east of Shoshone Mountain include Kiwi Mesa, Lookout Peak, Wahmonie Hills and Skull Mountain. The Wahmonie Hills are the remains of a volcano that deposited the tuff which makes up the bulk of Skull Mountain. This area is in the Great Basin section of the Basin and Range physiographic province (Snyder and Carr, 1982).

Human features visible on Yucca Mountain include the Exploratory Studies Facility (ESF) tunnel portal in Exile Hill below Yucca Mountain, the "subdock" drilling equipment yard and the highway that snakes up the ridge to the crest. The proposed high-level waste repository would extend from about the area of the subdock to just south of Highway Ridge. It is being designed to contain 77,000 tons of high-level, commercial power plant radioactive waste.

Yucca Mountain is a linear, fault-bounded, north-south trending hogback ridge composed of pyroclastic flows and falls erupted from a complex of six identified calderas located immediately to the north. The units range in age from middle to late Miocene (15 to 11.5 Ma), and are part of the Southwestern Nevada Volcanic Field. The Tertiary units are predominantly felsic tuffs and rhyolites, and can be up to 10,000 feet thick in some localities. Later episodes of volcanism were composed of mafic magmas, and Late Tertiary and Quaternary basalt flows and cinder cones occur around the periphery of the Yucca Mountain area. The major structural features in the area consist of normal faults, which frequently strike north-south and tend to be down to the west, overlain by a secondary set of strike-slip faults which trend northwest, and minor shear-type structures trending northeast. The area is located at the terminus of the Las Vegas Valley Shear Zone, and adjacent to the Walker Lane and Furnace Creek/Death Valley fault zones, resulting in a rather complex structural overprint.

Yucca Mountain is located in the northern portion of the Mojave Desert, in an arid scrubland that receives an average of only 10-15 cm of annual precipitation. There is no surface water in the area; all stream channels are ephemeral. Groundwater under Yucca Mountain occurs in an enclosed sub-basin bounded by Crater Flat on the west and Rock Valley/Ash Meadows on the east. Recharge occurs on the highland areas to the north, and flow is lateral in a general southerly direction. The upper unconfined aquifer consists of volcanic tuff and Tertiary alluvium, and the main point of discharge is Franklin Playa at the base of Eagle Mountain. Only one drill hole on the site penetrates the deeper, confined aquifer in the Paleozoic carbonates, but it appears to be part of the groundwater system that discharges at Furnace Creek in Death Valley. Water in the saturated zone under the proposed repository block of Yucca Mountain yields radiometric age dates of about 10,000 years. The unsaturated zone at Yucca Mountain is quite thick, with depths to the water table ranging from 1500 to 2000 feet over the proposed repository block area.

9:00 AM: Arrive at the Field Operations Center to check in and obtain safety equipment and water. This is a short (10-15 minute) stop only, so please don't tarry. Gather in Exhibit Room.

9:15 AM Depart for Yucca Mountain. Head north on 2nd Street toward the intersection with H-Road, then turn left on H-Road toward Yucca Mountain. As we cross Jackass Flats, some of the old nuclear rocket project facilities are visible. These are remnants from the NERVA, KIWI and Project Ranger experiments in the 1960's and 1970's that used nuclear energy to boost rocket thrust. Many of them actually worked quite well, although the exhaust was radioactive and an environmental hazard. There has been some recent talk about reviving these programs for interplanetary missions.

Pass the cement batch plant, which was recently constructed to provide concrete for the ESF. Just past the batch plant, cross Fortymile Wash, which is the main drainage for the watershed. It had a major runoff event on March 11, 1995. A pickup truck trying to cross the flow was washed a fair distance downstream and the driver had to be rescued while clinging to a creosote bush. This was the first time the wash had flowed since the summer of 1984. Turn left on the dirt road toward the top of Yucca Mountain.

9:30 AM **STOP 2:** **(10 min)** Fran Ridge terrace. Pull off to the side of the road by the turnoff to the LLNL heater block experiment to point out the volcanic units nicely exposed in Fran Ridge and Busted Butte. The stratigraphic section at Yucca Mountain is comprised of a thick sequence of pyroclastic rocks overlying a pre-Tertiary basement of Paleozoic sedimentary and possibly igneous intrusive rocks (Snyder and Carr, 1982). The volcanics were erupted from the Southwestern Nevada Volcanic Field, located north and west of Yucca Mountain, between 15 and 11.5 Ma. Deep boreholes and geophysical studies indicate that the Tertiary volcanic rocks in this area may be as much as 2 to 3 kilometers thick (Snyder and Carr, 1982). The volcanic plateau created by these eruptions was broken by a series of subparallel, north-south trending normal faults, with the downthrown side typically to the west. This produced a series of gently east-dipping hogbacks, such as Fran Ridge before us and Yucca Mountain itself. A second set of northwest trending, right-lateral strike slip faults is overlain on the north-south group, and are predominantly visible where they control drainage alignment at the northern end of Yucca Mountain (Galloway, et al.,1991). Most of the movement on both sets of faults occurred between 13 and 11.5 Ma (Scott and Castellanos, 1984), but there is also evidence of Quaternary and possibly Holocene episodes of movement on a number of these faults.

Visible before us in Fran Ridge is a major portion of the Paintbrush Group. It is composed of four main pyroclastic flow members and several pyroclastic falls. The basal, dark-colored member visible here is the Topopah Spring Tuff (unit Tpt on the geologic maps). It is the thickest member of the Paintbrush Group section at Yucca Mountain, and consists of fairly uniform, moderately to densely welded tuff of rhyolitic composition. The lighter-colored units above it are the nonwelded Pah Canyon (Tpp) and Yucca Mountain (Tpy) Tuffs, or their equivalents, mixed in with several air fall tuffs. These nonwelded tuffs and air falls in the middle of the sequence have similar geohydrologic and thermal-mechanical properties, and are frequently referred to in a group as the Ptn (Paintbrush Tuff nonwelded). The overlying darker unit is another thick welded tuff, the Tiva Canyon Tuff (map unit Tpc). These tuffs are also visible to the south in Busted Butte, where they are offset across a trace of the Paintbrush Canyon Fault. Both the Tiva Canyon and Topopah Spring welded tuffs are subdivided into a number of formal members and informal microunits based on degree of welding, crystallization, presence or absence of lithophysal cavities, fracturing characteristics and other lithostratigraphic features. The stratigraphy has recently been revised by Buesch and others (in press) to more accurately reflect the lithologic breaks in different units. Earlier geologic mapping by Scott and Bonk (1984) utilized weathering characteristics and color changes to differentiate between many of the microunits, but these features are not visible in drill core nor on the walls of a tunnel, so a better method was devised. This is a brief overview stop before we see these units in detail.

9:40 AM Return to vehicles and continue up the road (west) to the top of Yucca Mountain. Stop at the USW UZ-6s borehole location.

9:50 AM <u>STOP 3:</u> (30 min) Yucca Crest. Orientation and overview of geologic features around Yucca Mountain, from west to south to east: Solitario Canyon, Jet Ridge, Bare Mountain (with working gold mine), Crater Flat, Quaternary volcanic cinder cones (N-S: Black Cone, Red Cone, Little Cones and Lathrop Cone), Big Dune in the Amargosa Desert, the Funeral Mountains with California state line in front, Panamint Range behind and Death Valley in between, the Skeleton Hills, Striped Hills, Specter Range, Spring Mountains, Busted Butte, Fran Ridge, and Midway Valley. Jackass Flats and Skull Mountain are visible off to the east; Rainier Mesa can be glimpsed to the northeast. Pinnacle Ridge is to the north, and Chocolate Mountain is barely visible over the Prow.

Bare Mountain consists of a number of Late Proterozoic to Middle Paleozoic sedimentary and metasedimentary units (Monsen et al., 1992). From this viewpoint, the Middle Cambrian, gray-colored Bonanza King Dolomite is visible in the vicinity of the Stirling Mine. The Late Proterozoic Stirling Quartzite sits above the Bonanza King just south of the mine across a thrust fault. To the south, the units consist of the Nopah Formation, the Bonanza King again, the Zabriskie Quartzite in Wildcat Peak, and the Lower Cambrian Wood Canyon Formation. To the north of the Stirling Mine, the rocks consist of the Ordovician Pogonip Group, several Silurian and Devonian dolomites, and the clastic Devonian Eleana Formation. These Paleozoic and preCambrian units are assumed to subcrop beneath the Tertiary volcanics that make up the bulk of Yucca Mountain.

The surface rock here on Yucca Crest is the vitric zone of the crystal-rich member of the Tiva Canyon Tuff. Looking over the side of Solitario Canyon, one can see the other Tiva microunits, the bedded and non-welded tuffs, and the top of the Topopah Spring Tuff. The Solitario Canyon Fault, which is responsible for the Yucca Mountain hogback, runs along the base of the cliff and also through the center of the canyon. Several trenches are visible behind bright orange fencing on the canyon floor below us; spurs of the fault pass through the trenches. Recent mapping has found that the greatest displacement across the fault appears to be on the trace that runs along the base of the cliff. Plug Hill at the mouth of Solitario Canyon is capped with Rainier Mesa tuff, which was emplaced as a valley-fill after a period of major movement on the fault. There are several hundred feet of vertical offset across the fault at this locality, and the upthrown block is the east side, where we are standing. If you sight along the cliff to the head of the canyon, you can see that we are near the highest point of the hogback, and it declines to the north. This is important to keep in mind when we see the fault again later.

10:20 AM Pile into vehicle(s) and head down from Yucca Crest. Pull over to the side of Dune Wash Road to climb Boundary Ridge.

10:30 AM **<u>STOP 4:</u>** **(30 min)** Boundary Ridge. This hill exposes the transition from the top of the welded Topopah Spring Tuff into the overlying nonwelded ash flow and air fall units (Ptn) to the welded basal units of the Tiva Canyon Tuff. The total thickness of the section here is about 45 meters.

The thickness of a pyroclastic deposit influences the degree of welding and crystallization (Ross and Smith, 1961). Thicker pyroclastic deposits generally produce rocks that are moderately to densely welded due to compaction and slow cooling. Degassing and compaction in thick deposits forces the ash particles together while they are still hot and plastic, creating welded zones in the interior of these units. The insulating properties of the thick flow allow the amorphous volcanic glass to cool slowly and crystallize, developing a dense, non-porous, microcrystalline structure. Thinner deposits, on the other hand, cool more rapidly and are usually glassy or vitric. The lesser amount of overburden on thinner deposits results in pyroclastic rocks that preserve much of the original porosity of the loose volcanic ash and pumice. Porosities measured on Yucca Mountain rocks range from 2% to 60%, and permeabilities range across six orders of magnitude (Soeder, Flint and Flint, 1991). This wide variation in rocks of essentially the same origin is due mainly to differences in the degree of compaction, welding and devitrification.

Start up the hill in the nonlithophysal zone of the crystal-rich member of the Topopah Spring Tuff. (This equivalent to the "rounded" unit of Scott and Bonk's 1984 map). It consists of moderately to densely welded, devitrified tuff with flattened pumice fragments. The contact with the overlying Topopah Spring vitric zone is abrupt. The vitric zone consists of a lower, densely welded vitrophyre with abundant phenocrysts of sanidine, plagioclase and oxidized biotite. This unit is somewhat more mafic in composition than the rest of the flow, since it is on top and was the last material out of the magma chamber. The vitrophyre is the "caprock" of Scott and Bonk, and has a composition equivalent to a quartz latite. Porosity in the caprock is only about 1-2%, making it a possible hydrologic barrier. A red to black color transition is visible in the upper part of the vitrophyre due to different oxidation states of the iron in the rock.

A 10 meter thick, non- to partially welded pyroclastic flow deposit occurs immediately above the vitrophyre caprock, and is the upper part of the vitric zone in the crystal-rich member of the Topopah Spring Tuff. The base of this unit contains abundant pumice, and it grades upward into a tan-colored deposit with white pumice fragments. The red-stained areas at the top of this unit were originally identified as a surface weathering phenomenon, resulting from a period of exposure prior to burial by overlying deposits (Diehl and Chornack, 1990). However, a similar stained zone is well exposed at this horizon in the tunnel, and has been identified as a fumarole alteration. A number of more distinct erosion surfaces and paleosols do occur on some tuffs in this exposure.

The nonwelded, uppermost part of the Topopah Spring Tuff marks the boundary between the low porosity, densely welded and fractured lower Paintbrush welded hydrogeologic unit (Tsw) and the Paintbrush nonwelded hydrogeologic unit (PTn). Boundaries between the hydrogeologic units are not necessarily the same as stratigraphic boundaries. The PTn is characterized by high matrix permeability, low fracture density and low fracture permeability. The upper Paintbrush welded hydrogeologic unit (Tcw) begins in the basal vitric zone of the crystal-poor member of the Tiva Canyon Tuff, which we will encounter higher up the ridge.

A white pyroclastic air-fall deposit about 2 meters thick overlies the Topopah Spring Tuff nonwelded unit. The basal contact is quite sharp, and the ash grades from lapilli-sized (2mm-64 mm) pumice fragments near the base to finer material at the top. A weathered horizon is present at the top of this unit, and the contact is sharp.

A pyroclastic flow unit overlies the white air-fall, and may be the distal edge of the Pah Canyon Tuff (Diehl and Chornack, 1990). It is about 1 meter thick, with a light brown matrix, and contains white pumice fragments and dark, lithic rhyolite fragments. This mixture demonstrates the turbulent, unsorted nature of pyroclastic flows, compared to the more orderly, bedded air-fall deposit we looked at previously. No weathered horizon is present on this unit.

A 1-meter thick air-fall deposit overlies the possible Pah Canyon unit. It is finely laminated at the base with a weathered top, and shows sorting and graded bedding. The contact between the weathered top and the overlying unit is sharp.

The yellowish-brown unit above the air-fall is the nonwelded vitric base of the Tiva Canyon Tuff. (The Yucca Mountain Tuff is absent here.) This is sometimes referred to as the "shardy base" of the Tiva because of black glassy shards in the matrix. The degree of welding increases in an upward direction from nonwelded at the bottom to moderately welded at the top. This change is quite striking and easily demonstrated by "dinging" the rocks with a hammer. This zone represents the transition from the fracture-dominated permeability in the TCw hydrogeologic unit to matrix-dominated permeability in the PTn hydrogeologic unit. Welded tuffs typically have low matrix porosity but abundant fractures because they are so brittle, while nonwelded tuffs are much more porous and less fractured. The change in the nature of the flowpaths between these units results in high water saturations in the base of the Tiva Canyon Tuff.

The nonwelded to welded vitric zone is overlain by the columnar welded unit of the Tiva Canyon Tuff. The columnar morphology is the result of well-developed cooling joints. It grades from vitric at the base to devitrified at the top. The columnar unit typically contains abundant, flattened pumice fragments, vapor-phase quartz mineralization on some surfaces, and moderate to abundant feldspar spherulites in some of the pumice cavities. These are a late-stage vapor phase mineralization that nucleated onto feldspar "seed" phenocrysts in a mass of radial crystals. They are quite striking in thin section.

Note the appearance of the nonwelded and bedded tuffs here for comparison with what we will see at other locations around Yucca Mountain. Look at the texture, particle size and bedding in the air-fall tuffs at this site, which is relatively far from the caldera. Many of the units are undifferentiated at this location because they are too thin to map.

Zones of high water saturation and perched water in the Yucca Mountain unsaturated zone typically occur at or near the boundaries of hydrogeologic units. In the tunnel, there was a spectacular "wet zone" at the base of the Tiva Canyon Tuff near the termination of the fractures in the columnar unit, which extended down to an argillic horizon in the nonwelded vitric zone. A case could be clearly made that the change in flow mechanism from fractures in a low permeability matrix to pores in a high permeability, unfractured matrix was responsible for the high water content. Actual perched water is a bit less predictable: mobile water was perched on the basal vitrophyre of the Topopah Spring Tuff in USW UZ-14 borehole and in the Calico Hills Formation in other drillholes. Still, the case could be made that water was found where a significant change in hydrologic properties occurs within the rocks.

11:00 AM Return to vehicles, continue down dirt road to pavement and go left up Yucca Wash. Continue past Fran Ridge and Alice Ridge into Midway Valley. Turn right on the dirt road near the base of Exile Hill to the North Portal pad area of the Exploratory Studies Facility.

11:15 AM <u>**STOP 5:**</u> **(60 min)** The Exploratory Studies Facility (ESF) Tunnel. This will be a mined facility consisting of about 14 miles of tunnels, side drifts and test alcoves, and an array of underground rooms. The initial construction will consist of a 25-foot diameter tunnel looping approximately 5 miles into and under Yucca Mountain before emerging to the south. Experiments will be run to study geological, hydrological, thermal, mechanical, geochemical and physical attributes of rocks at the potential waste repository horizon. Excavation began in the spring of 1993 with a drill-blast "starter tunnel" 60 meters or 200 feet into the mountain. Test Alcove #1, 150 feet from the portal, was completed in January of 1994, for pneumatic permeability testing and gaseous-phase hydrochemistry sampling. Mining with the Tunnel Boring Machine (TBM) began in September, 1994, and has advanced a total of 3500 meters (11,500 feet) as of January 1, 1996. The North Ramp has been completed, and the TBM is excavating the main drift from north to south in the proposed repository horizon. This is the middle nonlithophysal zone in the crystal-poor member of the Topopah Spring Tuff (Tptpmn). Three other test alcoves have also been constructed: Alcove #2 is testing the Bow Ridge Fault, Alcove #3 is designed to test the transition from the Tcw to the Ptn, and Alcove #4 will test the transition from the Ptn into the Tsw. An additional alcove is planned to run off the main drift to test the Ghost Dance Fault, and a large thermal test area will be excavated in stages at the bottom of the North Ramp. Since the tunnel is an active construction area, be aware of activity that is taking place around you, and stay out of the path of mining equipment.

Mapping in the tunnel is being performed by geologists from the U.S. Bureau of Reclamation under an agreement with the USGS. The USBR has an enormous amount of tunnel mapping experience from years of water diversion work on dam projects. The fresh rock faces exposed by the TBM are cleaned with compressed air and mist, and mapping is done on a special gantry carried along on the trailing gear of the mining machine. This allows the geologists to view the rock without the conveyor belt, ventilation line or utility pipes being in the way. Four mapping activities are performed: 1) targets are placed on the ribs and back using a laser surveying device, 2) overlapping stereo photos are taken of the entire tunnel from invert to invert, 3) a detailed line survey is run at springline along the right rib of the tunnel, and 4) a full-periphery sketch map is drawn to show geologic features and natural fractures greater than 1 meter in length encountered by the tunnel. The data are used for structural geology, hydrologic modeling and engineering design inputs.

12:15 PM Leave the ESF and return to the paved road. Turn right and pass Exile Hill, then turn right again on the dirt road toward Trench 14. Stop at Trench 14 and call Ranch Control for permission to enter.

12:20 PM **STOP 6:** **(25 min)** Trench 14 in Midway Valley. This trench was originally dug to ascertain the frequency of seismic activity on the Bow Ridge Fault near the proposed site for the repository surface facilities. A DOE employee named Jerry Szymanski created a great deal of controversy when he proclaimed, on the basis of morphological evidence, that the calcite veins and associated mineralization along the fault were formed by hydrothermal fluids forced upward by volcanic activity. This implied that volcanic or tectonic events could raise the water table and flood the repository, and was a major argument used by the state in opposition to the site. Geochemical studies of the mineral veins by the USGS have revealed from oxygen isotope analysis that the material precipitated from cool water instead of hot fluids (Stuckless, et al., 1991). Trace element composition also indicates that the vein minerals are related far more closely to the local caliche layers than to the mineral deposits typically found around hot springs in the region (Peterman, et al., 1991; Marshall and Mahan, 1991). These findings strongly imply that the mineralization was formed by meteoric water percolating downward from the surface instead of hydrothermal fluids moving up from below. Additional evidence for the pedogenic origin of the silica and carbonate deposits in Trench 14 was nicely summarized from the work done by Emily Taylor of the USGS in Galloway and others (1991).

The ESF tunnel crosses the Bow Ridge Fault about 100 feet beneath Trench 14. Very little to no mineralization is visible on the fault in the tunnel. The footwall in the tunnel consists of the upper lithophysal zone of the Crystal Poor Member of the Tiva Canyon Tuff, and the hanging wall is composed of Rainier Mesa Tuff. (The footwall in the trench is the same unit of Tiva, but the hanging wall is composed of "calcrete", or carbonate-cemented alluvium.) No carbonate or silica veins like those in the trench are visible underground, and there are about three feet of breccia in the fault zone that won't even fizz under a drop of HCl. Jerry Szymanski was out here last spring to look at it and collect samples for isotopic and chemical analysis.

Look at the fracture fillings in detail. An important, unanswered question in the hydrology program is whether or not these act as channels for water to penetrate to great depths. There is some deformation and brecciation in the hanging wall on the north side of the trench caused by fault movement. Note also the well-developed layers of caliche in the soil.

Quaternary fault mapping is being performed by the USGS in the immediate Yucca Mountain region, as well as in a broader area within 100 km of Yucca Mountain. All faults and lineaments visible from photogeologic surveys have been walked out and mapped. One of the reasons for running the photographic survey was to seek a possible interconnection between the northwest-trending faults and the N-S faults. It was initially thought that the N-S faults had increased displacement toward the south, but mapping has shown that the most active areas of these faults tend to be in the south-central regions. Most of the N-S faults are normal, with a left oblique (lateral) component of 50-65° as shown by slickensides. Studies were carried out on five major Yucca Mountain faults: the Bow Ridge, Solitario Canyon, Paintbrush Canyon, Stagecoach Road, and the Windy Wash Faults. The more distant faults around Yucca Mountain that were studied and mapped include the Bare Mountain Fault in Crater Flat, the Furnace Creek and Death Valley Fault system, and the northeast-trending Rock Valley and Mine Mountain Faults.

The path of the North Ramp tunnel can be discerned while leaving Trench 14 by sighting on the UE-25 NRG#4 borehole visible in the distance on top of Azreal Ridge. The tunnel alignment runs directly under the trench at an angle to the northwest and passes about 50 feet south of the borehole. The top of the Topopah Spring Tuff occurs in the tunnel near the location of the NRG#4 borehole.

12:45 - 1:15 PM Lunch time. We can either eat here at Trench 14 if the weather is unpleasant and we want the shelter of the trench, or we can go up to our next stop at Mile High Mesa and eat there. We will decide on the spot. One way or the other, we'll take 30 minutes for lunch, and start in on Mile High Mesa afterward.

12:45-1:15 PM Lunch. 1:15-1:30 PM Travel to Mile High Mesa. -- or --
12:45-1:00 PM Travel to Mile High Mesa. 1:00-1:30 PM Lunch

1:30 PM **STOP 7: (60 min)** Mile High Mesa, trench near borehole USW GA-1. This small trench cuts the Solitario Canyon Fault; the same fault we saw from Yucca Crest. However, the fault at this location looks very different from what we saw before. The displacement here is quite small, with the upper portions of the Tiva Canyon Tuff on both sides. The nonwelded vitric zone of the Crystal Rich Member is on the east side of the fault, and the densely welded vitrophyre of the Crystal Rich Member is on the west side. The throw across the fault at this location is only 20 to 30 feet, and the upthrown side is to the west, not to the east as we noted on Yucca Crest.

So what's the story here? The Solitario Canyon Fault is a rare example of what is known as a "scissors fault". The fault has a strong rotational component, such that the southern portion is upthrown to the east, and the northern portion is upthrown to the west. We are just north of the pivot point. Severing of the fault by the caldera boundary to the north possibly allowed the block to rotate in this manner. True scissors faults are quite rare, and this may be the only one you'll ever see.

Hike down the strike of the fault to the north about a quarter mile, passing an old seismic line calibration area and another small trench. At the USW UZN-11 borehole, walk to the edge of the ravine and pause for an overview.

This is arguably the most interesting spot geologically on the entire field trip, and is probably the best central location to get an overall feeling for the structure and stratigraphy of the area. Below is Yucca Wash, a northwest-trending, fault-controlled drainage along the caldera boundary. (Isostatic gravity surveys indicate that there may be a structural fold through here as well.) Across the wash is Pinnacles Ridge, which is composed of intracaldera moat deposits, rhyolite flows and lahars. The cauldron boundary of the Claim Canyon caldera segment (source of the Paintbrush Group) of the Southwestern Nevada Volcanic Field can be seen in Chocolate Mountain at the white ash deposit. There are at least five nested calderas (with possibly a sixth) ranging in age from roughly 15 Ma to 11.5 Ma. Not visible behind Pinnacles Ridge is Timber Mountain, the resurgent rhyolite dome in the center of the youngest caldera. The Timber Mountain caldera is the source of the Rainier Mesa Tuff.

Fortymile Wash Canyon can be seen to the east, cutting past the Calico Hills. The Calico Hills are composed of rhyolite flows, nonwelded tuff breccias and pyroclastic falls which are somewhat older than the rocks of the Paintbrush Group. There was a significant hiatus between the eruption of the Calico Hills Formation and the Paintbrush Group. The magma body was apparently still close to the surface, and much of the Calico Hills has been hydrothermally altered, resulting in the striking colors. The altered tuff breccias are silicified in parts, and contain abundant zeolite mineralization elsewhere. The Calico Hills Formation consists mostly of rhyolite flows to the north and east, but the zeolitic tuff breccias extend under Yucca Mountain. The zeolites consist primarily of clinoptilolite and mordenite, which act as "molecular sieves" to trap and hold dissolved ions in their structure. Large ions, such as those from transuranic nuclear waste, would be preferentially trapped in the zeolite crystal structure, and the zeolite-bearing tuffs are considered a natural barrier to radionuclide migration. The water table under the proposed repository block occurs primarily within the Calico Hills Formation.

The surface trace of the Solitario Canyon Fault passes through the gully we are standing on. The east side is comprised of the welded vitric zone of the crystal-rich member of the Tiva Canyon Tuff (caprock), while across the gully is the pyroclastic fall above the Pah Canyon Tuff. This represents a displacement of hundreds of feet; the Tiva Canyon basal columnar unit is visible on the other side of the fault quite a distance up Castellated Ridge. The displacement across the fault is considerable even at this short distance from the trench at GA-1.

The main part of the Pah Canyon Tuff is visible in the cliff face below; it is hundreds of feet thick here, and contains a welded zone in the center of the flow. Note how different the Pah Canyon Tuff looks at this location near the source caldera, compared to the distal edge of the flow we saw earlier on Boundary Ridge to the south.

Cross the fault and climb a short distance up Castellated Ridge toward the Prow to look at the air-fall tuff and the Yucca Mountain Tuff above it. There are thin, structured laminae at the top of the air-fall tuff near the contact with the overlying Yucca Mountain Tuff. These are probably reworked fluvial or lacustrine deposits. The basal part of the Yucca Mountain Tuff is comprised of a 5 to 10 foot thick air-fall pumice (Christiansen and Lipman, 1965); the pumice size decreases in an upward direction, as is typical of an air-fall deposit. This is one of the most striking examples of upward-fining in a pyroclastic fall on the mountain. The remainder of the Yucca Mountain Tuff is a gray nonwelded pyroclastic flow. Above the Yucca Mountain Tuff, we again encounter the welded Tiva Canyon Tuff. It is actually somewhat thinner here than in other places on the mountain, which may be due to the development of topographic relief from fault activation. By the time the Rainier Mesa Tuff at the top of the section was deposited, the topography was fairly steep.

From our perch on Castellated Ridge, we can look back and see Mile High Mesa and the northwest-trending ridges below us. There is a very steep hydraulic gradient through Mile High Mesa, Bleach Bone Ridge and Azreal Ridge, where the water table descends in a southeasterly direction from 1030 meters above sea level in USW G-2 to only 730 meters above sea level at USW H-1 in Drillhole

Wash. It is at the 730 meter level over most of the rest of the site. This 300-meter (1000 feet) drop in the potentiometric surface over a distance of only about two kilometers is quite unusual, and the reasons for it are not clearly understood (Fridrich, Dobson and Dudley, 1991). Geophysical data indicates that there is a gravity high, a magnetic anomaly and a thermal low in the area. The thermal low is presumably due to the water table descending from lower-temperature shallow depths into deeper, hotter levels, but the gravity and magnetic data are contradictory and inconclusive. Still, Fridrich feels that there is enough stratigraphic and geophysical evidence to postulate the existence of a large, deep fault through this area. It is unclear at this point, however, if the water is actually descending along the fault, or if the fault is acting like a dam to hold the water back and keep the water table higher than it would be otherwise. These scenarios have interesting and different implications for the hydrology of Yucca Mountain.

2:30 PM Return to vehicles, proceed back down Bleach Bone Ridge to paved road. Cross this road, and continue up the dirt road toward the UE-25 UZ#16 borehole site. Take the left (south) fork at UZ-16, and continue up the wash to the USW UZ-7A drill pad. Park on the pad and walk over to the vertical cut in Broken Limb Ridge.

3:00 PM **STOP 8:** This is known among the USGS project geologists as "The Wall." This cut was originally planned merely to construct the drill pad in this narrow wash, but a little bit of checking revealed that if it was oriented properly, it could also be used to reveal significant features on the Ghost Dance Fault. The main trace of the Ghost Dance cuts through at the breccia zone in the notch. Displacement across the fault here is on the order of 50 feet, downthrown on the west side. The footwall is the lower lithophysal zone of the crystal-poor member of the Tiva Canyon Tuff, and the hanging wall is the densely-welded, middle nonlithophysal zone of the crystal-poor member (identified in the Scott and Bonk map of 1984 as the "clinkstone").

The intense fracturing in the hanging wall side of the fault is caused by a number of factors, which include the exceptionally brittle rock, the convergence of another fault strand forming a wedge in the rock mass, and the fact that there appears to be a kink or bend in the surface trace of the Ghost Dance Fault across this valley. Warren Day of the USGS has an operating hypothesis that these fault traces widen out or branch at the surface into "horsetails", and that the fault zones at depth are actually much narrower. Indications of this have been seen in the ESF tunnel across the Bow Ridge Fault and also at the Drillhole Wash Structure, and there is some additional supporting evidence from the seismic reflection lines. (A sketch of how the horsetailing might work is included in the handout).

The borehole and instrument shelter at the UZ-7A location are monitoring hydrologic conditions deep in the unsaturated zone. The tunnel will pass through here just west of the drill pad, and the downhole instruments will measure changes in temperature, pressure and humidity in the rock mass before and after the excavation passes through this area. This is being done at other locations as well.

3:30 PM. Leave the USW UZ-7A borehole site and return to the paved road. Turn left and drive back to the project area facilities. Stop at the Hydrologic Research Facility.

3:50 PM **STOP 9:** **(40 min)** Arrive at the HRF for refreshments and bathrooms. After a few moments, gather by the main office to tour the building.

The Hydrologic Research Facility (HRF) was established by the U.S. Department of Energy in 1989 to provide office and laboratory space for Federal employees and contractors of the U.S. Geological Survey (USGS) working on the Yucca Mountain Project. Only a few Nevada-based research and technical personnel remain permanently assigned to the HRF, but the numbers can still increase significantly during field season activities or because of special project events.

USGS hydrologic research at Yucca Mountain falls into two main groups: Saturated Zone (SZ) Hydrology, and Unsaturated Zone (UZ) Hydrology. Saturated Zone studies are investigating recharge, discharge, flow rates, direction of flow, and groundwater chemistry. These studies will help to better define the nature of the groundwater system under Yucca Mountain.

Unsaturated Zone research is studying the amount of water which enters the mountain from rain or snow (infiltration), and determining the rate at which it makes its way down through the unsaturated rock to the water table (percolation). The on-site personnel measure precipitation, run-off, natural and artifical infiltration rates, and evaportranspiration. Moisture content, hydraulic and physical properties of the soil and rock material are measured in a well-equipped hydrology lab. The infiltration work includes a meteorology program to investigate the relationships between weather patterns that affect southern Nevada and the nature of precipitation on Yucca Mountain.
Other activities in the HRF include instrumentation and calibration, geochemistry, and assembly of a geographic information system (GIS) database.

4:30 PM Leave the HRF and return to Mercury.

5:00 PM Arrive in Mercury to exit the Test Site. All visitor's badges must be turned in, and everyone must pass through security.

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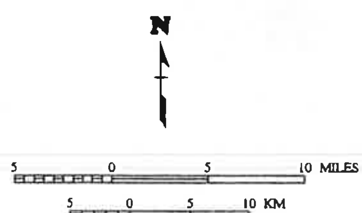


YUCCA MOUNTAIN
SITE CHARACTERIZATION PROJECT

SHADED RELIEF MAP
OF
NEVADA TEST SITE
AND VICINITY

L A S V E G A S B O M
A N D G U N N E
THE PROW
MILE-HIGH MESA
YUCCA WASH
ISOLATION R.
SEVER WASH
DRILLHOLE WASH
JET RIDGE
SOLITARIO CANYON
CREST
NORTH PORTAL
MIDWAY VALLEY
CALICO HILLS
BOW RIDGE
FRAN RIDGE
DUNE WASH
JACKASS FLATS
FORTYMILE WASH
CRATER FLAT
BUSTED BUTTE

Table 1: Precambrian and Paleozoic stratigraphic section in the field trip vicinity (after Winograd and Thordarson, 1975).

Period	Age (Ma)	Epoch		Stratigraphic Unit and Description
PALEOZOIC				
	'286	Pennsylvanian		Tippipah Limestone - correlative with the Bird Spring Formation, 2000 m thick, limestone interbedded with pebbly and silty limestone layers.
	320	Mississippian		Monte Cristo Limestone - approximately 300 m thick, dark- to light-gray, medium- to coarse-grained, highly fossiliferous, cherty limestone.
	360	Devonian	late	Eleana Formation - minimum thickness of 2350 m, shale, argillite, siliceous siltstone, quartzite, conglomerate and minor amounts of limestone.
			mid to late	Devil's Gate Limestone - 300 to 500 m thick, cliff forming, light- to dark-gray to blue-gray limestone with minor amounts of dolomite.
				Nevada Formation - coeval with the Sultan Limestone - Ironside Dolomite Member, 40 m thick in the Goodsprings district, dolomite.
	438	Ordovician	mid to late	Ely Springs Dolomite - 90 to 150 m thick, medium- to dark-gray, aphanitic- to fine-grained, laminated to thin-bedded dolomite with irregular chert lenses.
			mid	Eureka Quartzite - 30 to 140 m thick, white- to gray-orange, vitreous- to fine-grained quartzite. Grains well rounded and sorted, local faint cross bedding.
			early to mid	Pogonip Group - consisting of the Antelope Valley Limestone, Ninemile Formation, and Goodwin Limestone, 465 m thick at Bare Mountain, limestone, shaley limestone and minor amounts of dolomite.
	505	Cambrian.	late	Nopah Formation - 580 m thick at Bare Mountain, includes the Dunderberg Shale Member (50 m thick), varicolored dolomite underlain by shale and minor amounts of limestone and sandstone.
			mid to late	Bonanza King Formation - 1160 m thick at Bare Mountain, thin to thick bedded dolomite with scattered limestone beds, sandy layers and cherty bands.
			early to mid	Carrara Formation - 540 m thick at Bare Mountain, interstratified shale and limestone.
			early	Zabriski Quartzite - 350 m thick at Bare Mountain, homogeneous pale-red, fine- to coarse-grained quartzite.
			early	Wood Canyon Formation - 640 m thick, fine- to medium grained clastics.
PRECAMBRIAN				
	570		late	Stirling Quartzite - 975 to 1040 m thick near the Spring Mountains, gray to pink quartzite with minor amounts of conglomerate and siltstone.
			late	Johnnie Formation - 1280 m thick near the Spring Mountains, fine-grained quartzite, sandstone, siltstone, and shale with interbedded thin dolomite.

TABLE 1: SUMMARY OF MAJOR STRATIGRAPHIC UNITS OF THE SWNVF
[* Indicates newly defined with formal stratigraphic name. No entry in Old column indicates that current usage is unchanged]

Assemblage Symbol	Current	Old (previous usage)	Volcanic center
Ts	Stonewall Flat Tuff		Stonewall Mountain caldera complex
	Civet Cat Canyon Member		
	Spearhead Member		
Tt	Thirsty Canyon Group	Thirsty Canyon Tuff	Black Mountain caldera
	Gold Flat Tuff	Gold Flat Member	
	Trail Ridge Tuff	Trail Ridge Member	
	Pahute Mesa Tuff	Pahute Mesa Member	
	Rocket Wash Tuff	Rocket Wash Member	
Tf	Volcanics of Fortymile Canyon		Diverse vent areas
	Beatty Wash Formation*	rhyolite of Beatty Wash	
Tm	Timber Mountain Group	Timber Mountain Tuff	Timber Mountain caldera complex
	Ammonia Tanks Tuff	Ammonia Tanks Member	Ammonia Tanks caldera
	Rainier Mesa Tuff	Rainier Mesa Member	Rainier Mesa caldera
Tp	Paintbrush Group	Paintbrush Tuff	
	Tiva Canyon Tuff	Tiva Canyon Member	Claim Canyon caldera
	Yucca Mountain Tuff	Yucca Mountain Member	
	Pah Canyon Tuff	Pah Canyon Member	
	Topopah Spring Tuff	Topopah Spring Member	Uncertain
Ta	Calico Hills Formation*	tuffs and lavas of Calico Hills, Area 20	
Tw	Wahmonie Formation		Wahmonie volcano
			Silent Canyon caldera complex
Tc	Crater Flat Group	Crater Flat Tuff	
	Prow Pass Tuff	Prow Pass Member	
	Bullfrog Tuff	Bullfrog Member(Stockade Wash Tuff)	Area 20 caldera
	Tram Tuff	Tram Member	(Prospector Pass caldera complex?)
Tb	Belted Range Group	Belted Range Tuff	
	Dead Horse Flat Formation*	tuff and lava of Dead Horse Flat/ volcanics of Saucer Mesa	
	Grouse Canyon Tuff	Grouse Canyon Member	Grouse Canyon caldera
	bedded member	tunnel bed 5	
	comendite of Split Ridge	rhyolite of Split Ridge	
Tr	Lithic Ridge Tuff		Uncertain
	Lava of Tram Ridge	quartz latite lava and unit C tuff	
Tn	Tunnel Formation*	tunnel beds 3 and 4	
Tu	Tub Spring Tuff	Tub Spring Member	Uncertain
To	tuff of Yucca Flat		
	Redrock Valley Tuff		Uncertain

TABLE 3: $^{40}Ar/^{39}Ar$ AGE DETERMINATIONS

Unit	Sample	Mineral	Age (Ma)	Uncertainty
Spearhead Member	N80A	sanidine	7.5	0.03
Rocket Wash Tuff	Age 11	sanidine	9.4	0.04
Ammonia Tanks Tuff	Average of 3 sanidines pooled		11.45	0.03
Rainier Mesa Tuff	Average of 3 sanidines pooled		11.6	0.03
Tiva Canyon Tuff	Average of 3 sanidines pooled		12.7	0.03
Topopah Spring Tuff	Average of 4 sanidines pooled		12.8	0.03
Calico Hills Fm.	RW19f2-m	sanidine	12.9	0.04
Wahmonie Formation	FB25a6	biotite	13.0	0.10
Bullfrog Tuff	Average of 2 sanidines pooled		13.2	0.03
Dead Horse Flat Fm.	DS19d15	sanidine	13.5	0.02
Grouse Canyon Tuff	DS18a1	sanidine	13.7	0.04
Comendite of Split Ridge	DS19f9	sanidine	13.85	0.02
Lithic Ridge Tuff	TSV-417B	sanidine	13.85	0.07
Lava of Tram Ridge	RW19f9	biotite	14.0	0.09
Tub Spring Tuff	DS15e6	sanidine	14.9	0.04
Tuff of Yucca Flat	FB16a3	sanidine	15.05	0.06
Redrock Valley Tuff	Age 13	sanidine	15.1	0.05

GENERALIZED STRATIGRAPHIC SECTION
YUCCA MOUNTAIN AND VICINITY

AGE	UNIT	MAP SYMBOLS
Quaternary	Quaternary alluvium/colluvium	Qac
	------ unconformity ------	
10 Ma	Late Miocene basalt dikes and flows	Tb
	------ unconformity ------	
	Timber Mountain Tuff	
11.5 Ma	Rainier Mesa Member (eastern ridges)	Tmr
	Tuff Unit "X" pyroclastic flow	Tpki
	Pre-Tuff "X" pyroclastic fall	Tpbt5
	------ unconformity ------	
	Paintbrush Group	
12.7 Ma	Tiva Canyon Tuff	Tpc
	Crystal-rich member (qtz latite)	Tpcr
	Vitric zone	Tpcrv
	Nonwelded subzone	Tpcrv3
	Mod. welded subzone	Tpcrv2
	Vitrophyre subzone	Tpcrv1
	Nonlithophysal zone	Tpcrn
	Crystal-poor member (hi-Si rhyolite)	Tpcp
Middle Miocene (Tertiary)	Upper lithophysal zone	Tpcpul
	Middle nonlith zone(clinkstone)	Tpcpmn
	Lower lithophysal zone	Tpcpll
	Lower nonlith zone	Tpcpln
	Hackly subzone	Tpcplnh
	Columnar subzone	Tpcplnc
	Vitric zone	Tpcpv
	Vitrophyre subzone (local)	Tpcpv3
	Welded subzone (shardy base)	Tpcpv2
	Nonwelded subzone	Tpcpv1
	Pre-Tiva pyroclastic fall	Tpbt4
	Yucca Mountain Tuff	Tpy
	Pre-Yucca pyroclastic fall	Tpbt3
	Pah Canyon Tuff (top weathered)	Tpp
	Pre-Pah pyroclastic fall	Tpbt2
12.8 Ma	Topopah Spring Tuff	Tpt
	Crystal-rich member (qtz latite)	Tptr
	Vitric zone	Tptrv
	Nonwelded subzone	Tptrv3
	Welded subzone	Tptrv2
	Vitrophyre subzone	Tptrv1
	Nonlithophysal zone	Tptrn
	Lithophysal zone	Tptrl
	Crystal-poor member (hi-Si rhyolite)	Tptp
	Upper lithophysal zone	Tptpul
*Proposed Repository Horizon	*Middle nonlith zone	Tptpmn
	*Lower lithophysal zone	Tptpll
	Lower nonlith zone	Tptpln
	Vitric zone	Tptpv
	Pre-Topopah pyroclastic fall	Tpbt1
	------ unconformity ------	
12.9 Ma	Calico Hills Formation	Trc
	Pyroclastic flows (5 units)	
	Basal pyroclastic fall	
	Basal volcaniclastic sandstone	
13.0 Ma	Wahmonie Formation (east of Yucca Mt.)	Tw
	------ unconformity ------	
13.2 Ma	Crater Flat Group	
	Prow Pass Tuff	Tcp
	Bullfrog Tuff	Tcb
	Tram Tuff	Tct

SOURCES: Geslin, J.K. & Moyer, T.C., Summary of Lithologic Logging of New and Existing Boreholes at Yucca Mountain, NV: USGS Open File Report 94-451, 1994. Moyer, T.C. & Geslin, J.K., Lithostratigraphy of the Calico Hills Formation and the Prow Pass Tuff at Yucca Mountain, NV: USGS OFR 94-460, 1994. Frizzell, V.A. and Shulters, J., Geologic Map of the Nevada Test Site, Southern Nevada: USGS Misc. Investigations Map I-2046, 1990. (DJS, rev 1/96)

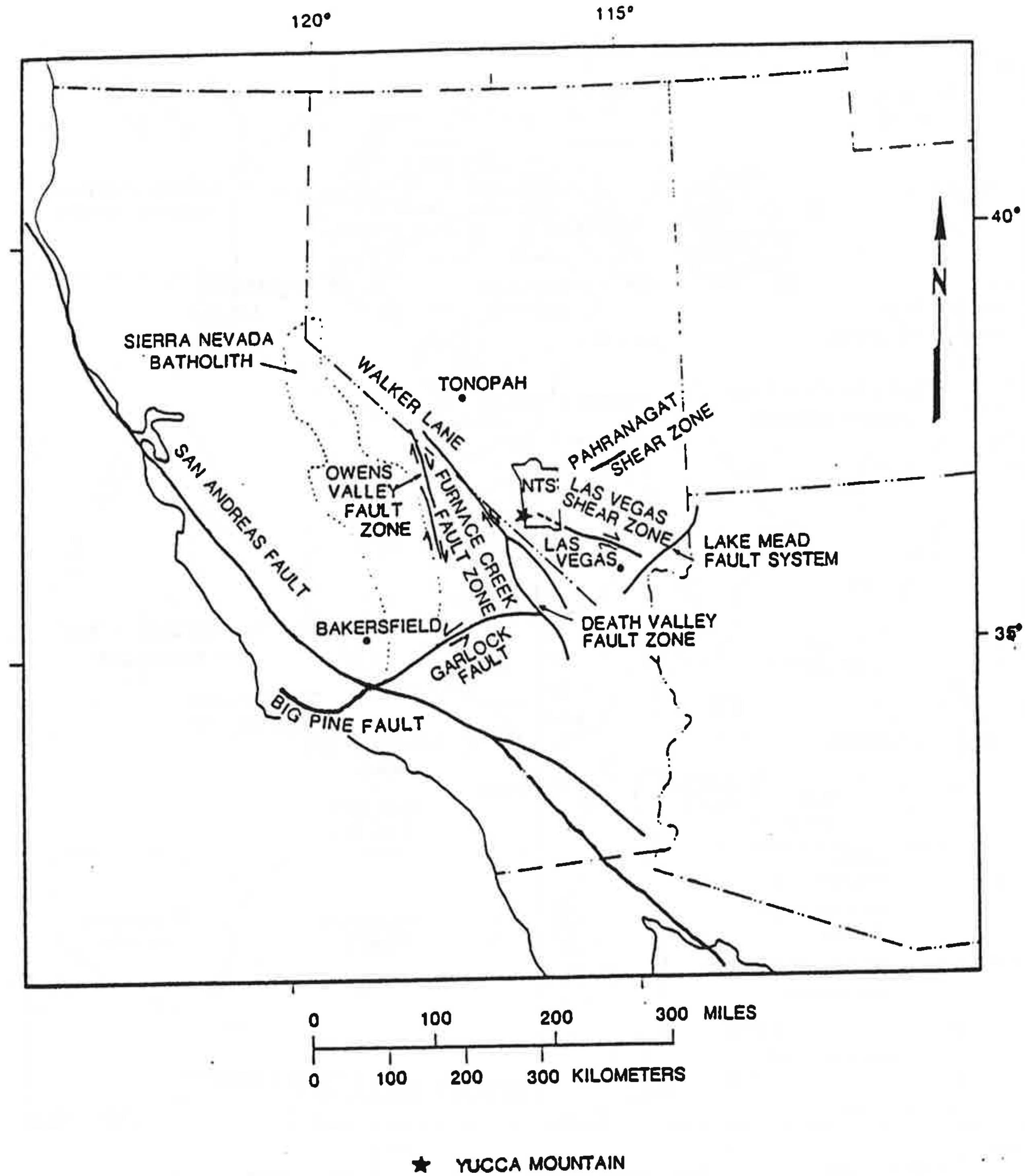
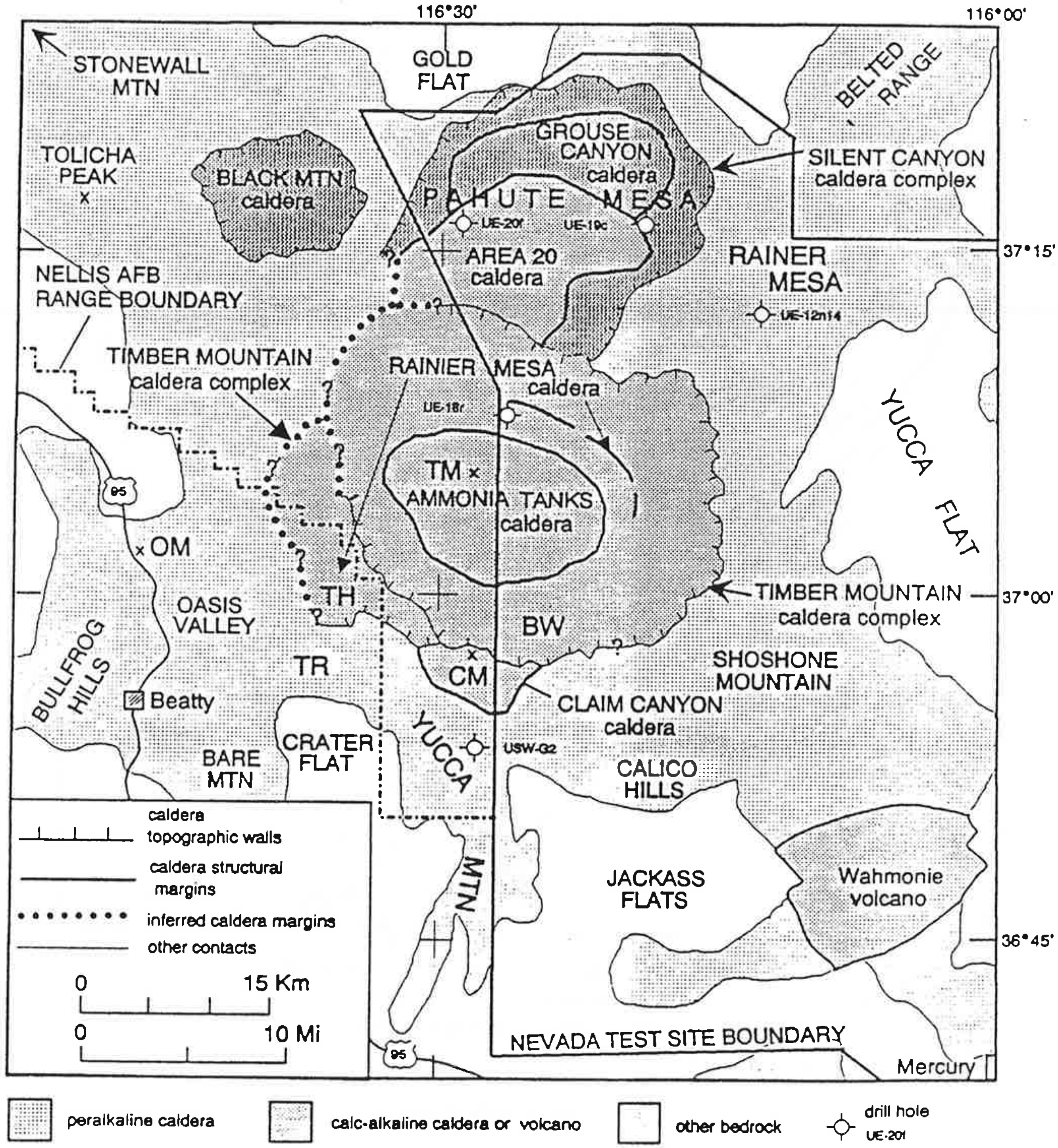

120°
115°
40°
35°
N
SIERRA NEVADA BATHOLITH
WALKER LANE
TONOPAH
PAHRANAGAT SHEAR ZONE
OWENS VALLEY FAULT ZONE
FURNACE CREEK FAULT ZONE
NTS
LAS VEGAS SHEAR ZONE
LAS VEGAS
LAKE MEAD FAULT SYSTEM
SAN ANDREAS FAULT
BAKERSFIELD
DEATH VALLEY FAULT ZONE
GARLOCK FAULT
BIG PINE FAULT
0 100 200 300 MILES
0 100 200 300 KILOMETERS
★ YUCCA MOUNTAIN

Fig. 1



116°30'
116°00'
STONEWALL MTN
GOLD FLAT
BELTED RANGE
TOLICHA PEAK
BLACK MTN caldera
GROUSE CANYON caldera
PAHUTE MESA
SILENT CANYON caldera complex
UE-20f
UE-19c
AREA 20 caldera
RAINIER MESA
37°15'
NELLIS AFB RANGE BOUNDARY
UE-12n14
TIMBER MOUNTAIN caldera complex
RAINIER MESA caldera
UE-18r
YUCCA FLAT
TM
AMMONIA TANKS caldera
OM
OASIS VALLEY
TH
TIMBER MOUNTAIN caldera complex
37°00'
BW
BULLFROG HILLS
TR
CM
SHOSHONE MOUNTAIN
Beatty
CLAIM CANYON caldera
CRATER FLAT
BARE MTN
YUCCA MTN
USW-G2
CALICO HILLS
caldera topographic walls
caldera structural margins
inferred caldera margins
other contacts
JACKASS FLATS
Wahmonie volcano
36°45'
0
15 Km
0
10 Mi
95
NEVADA TEST SITE BOUNDARY
Mercury
peralkaline caldera
calc-alkaline caldera or volcano
other bedrock
drill hole
UE-20f

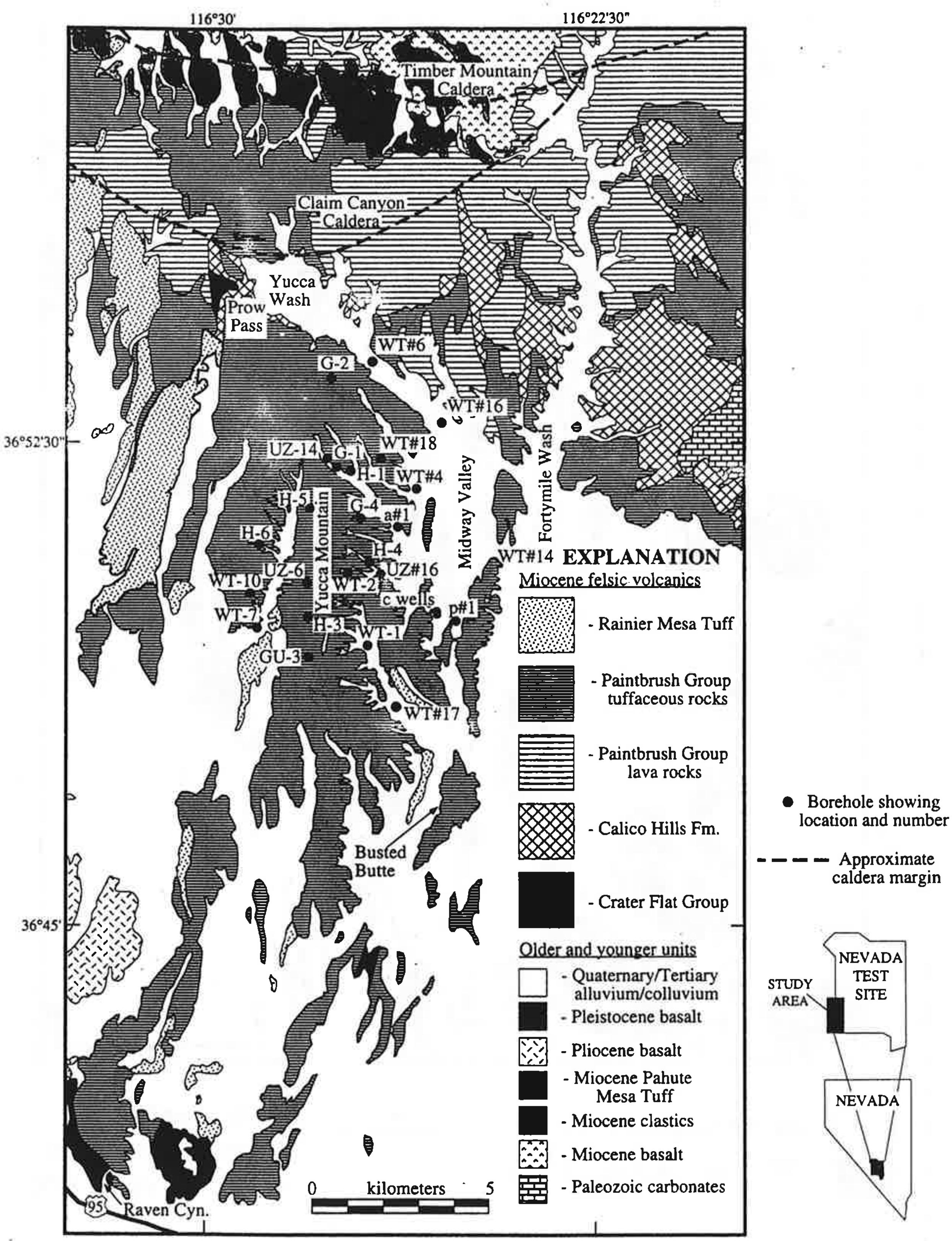
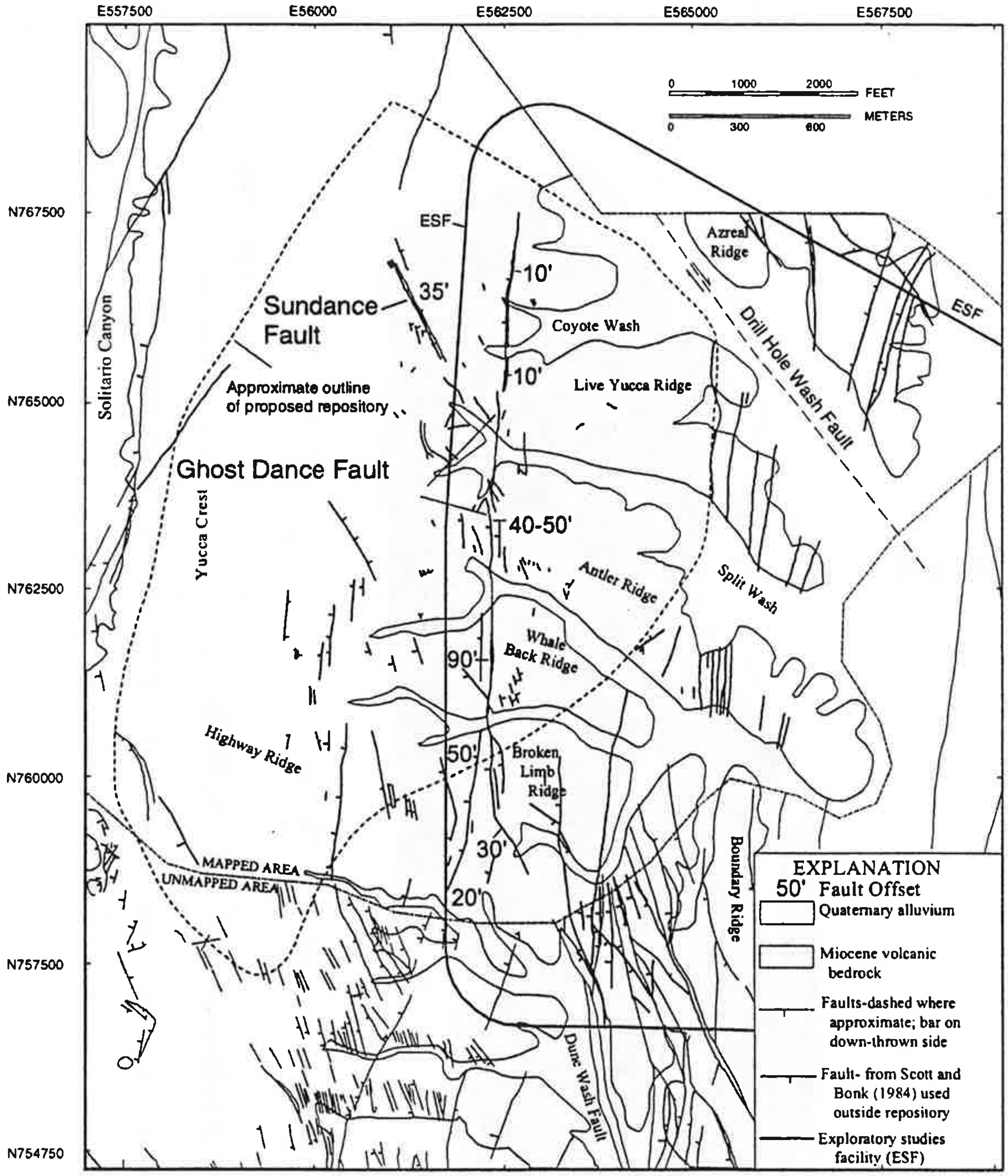


Figure 1. Simplified geologic map showing the distribution of major lithostratigraphic units in the Yucca Mountain area (modified from Frizzell and Shulters, 1990).

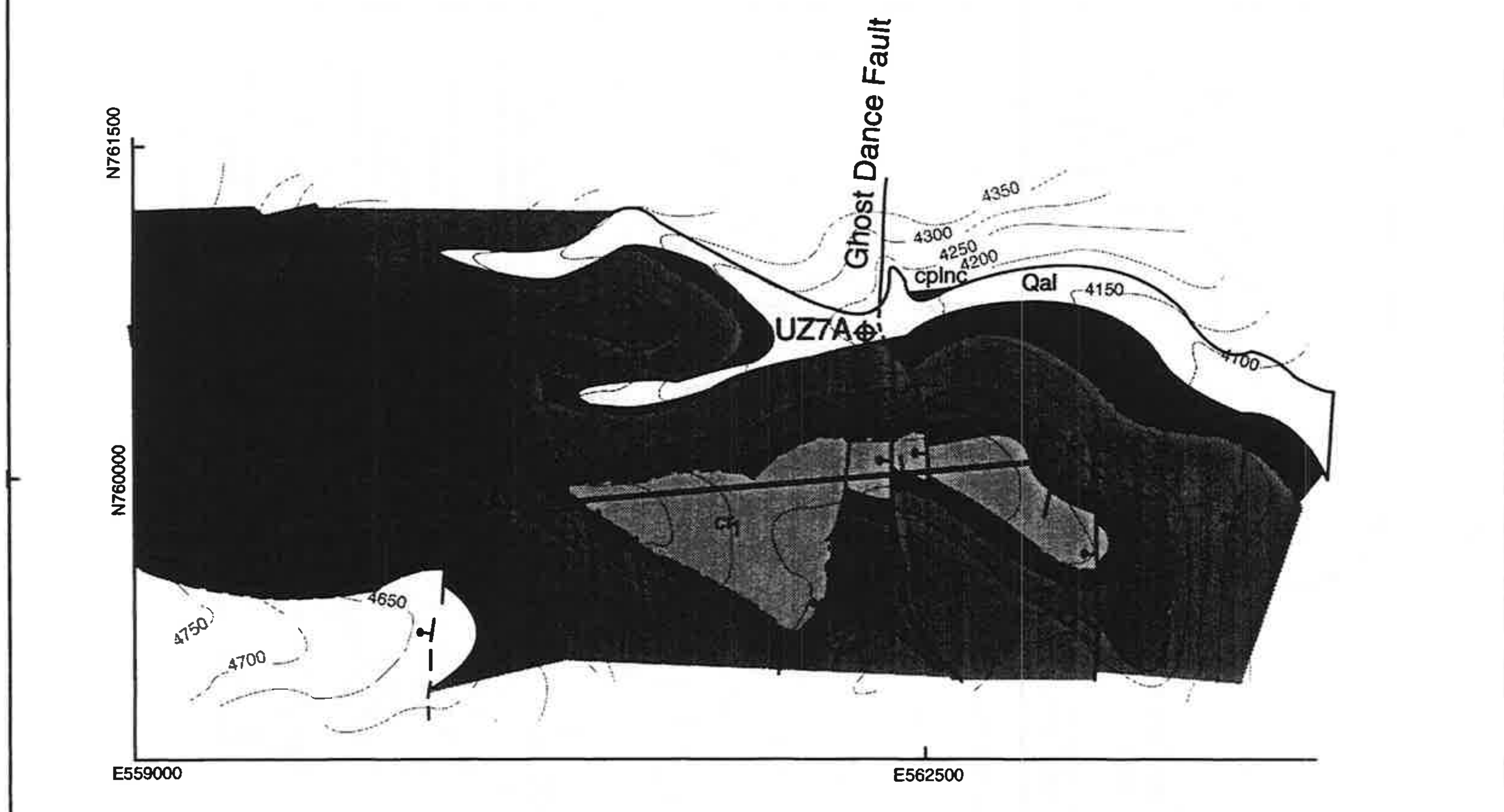
Quaternary alluvium

Miocene volcanic strata

Faults, dashed where inferred; bar on downthrown side

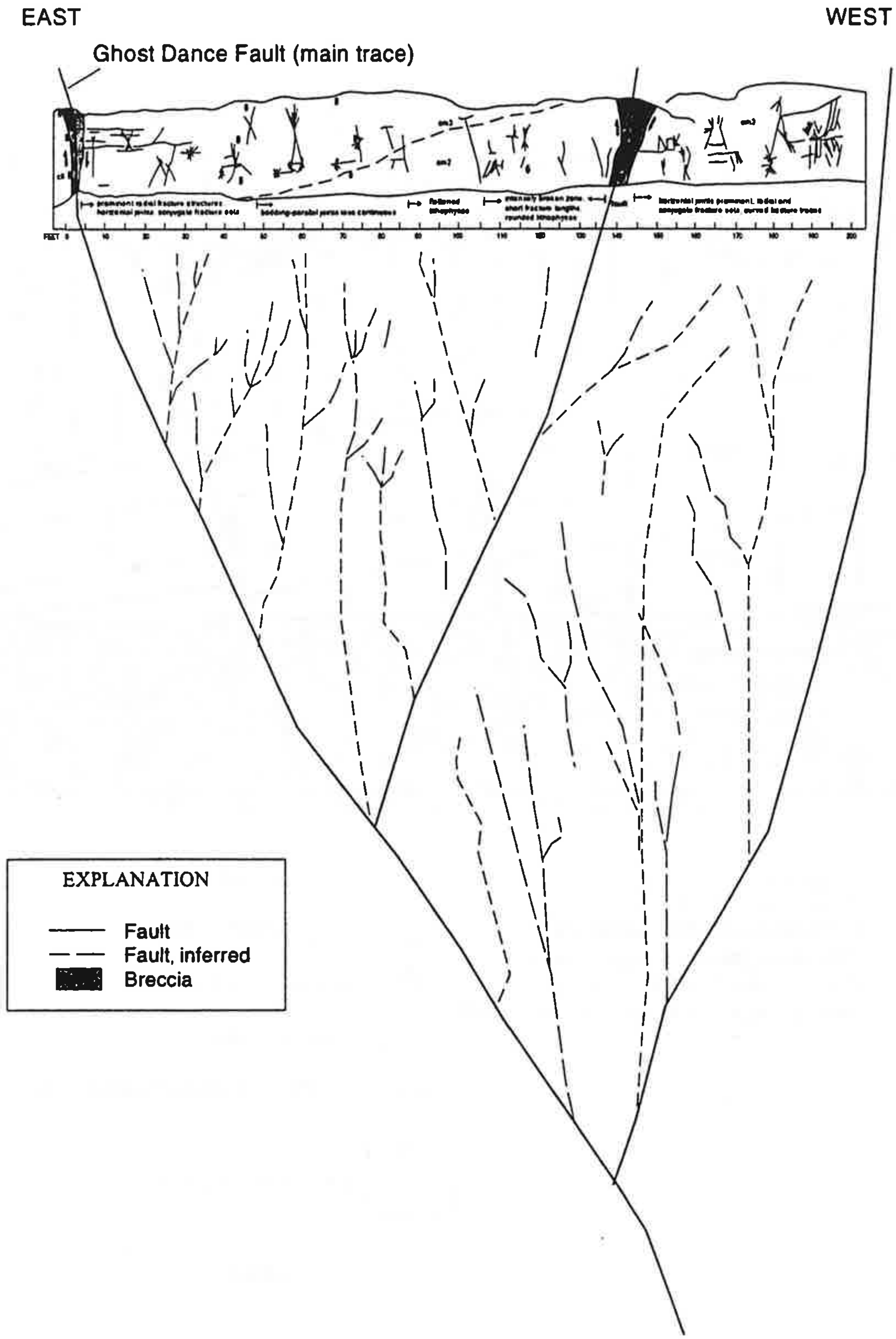


Modified after Day and others, 1995



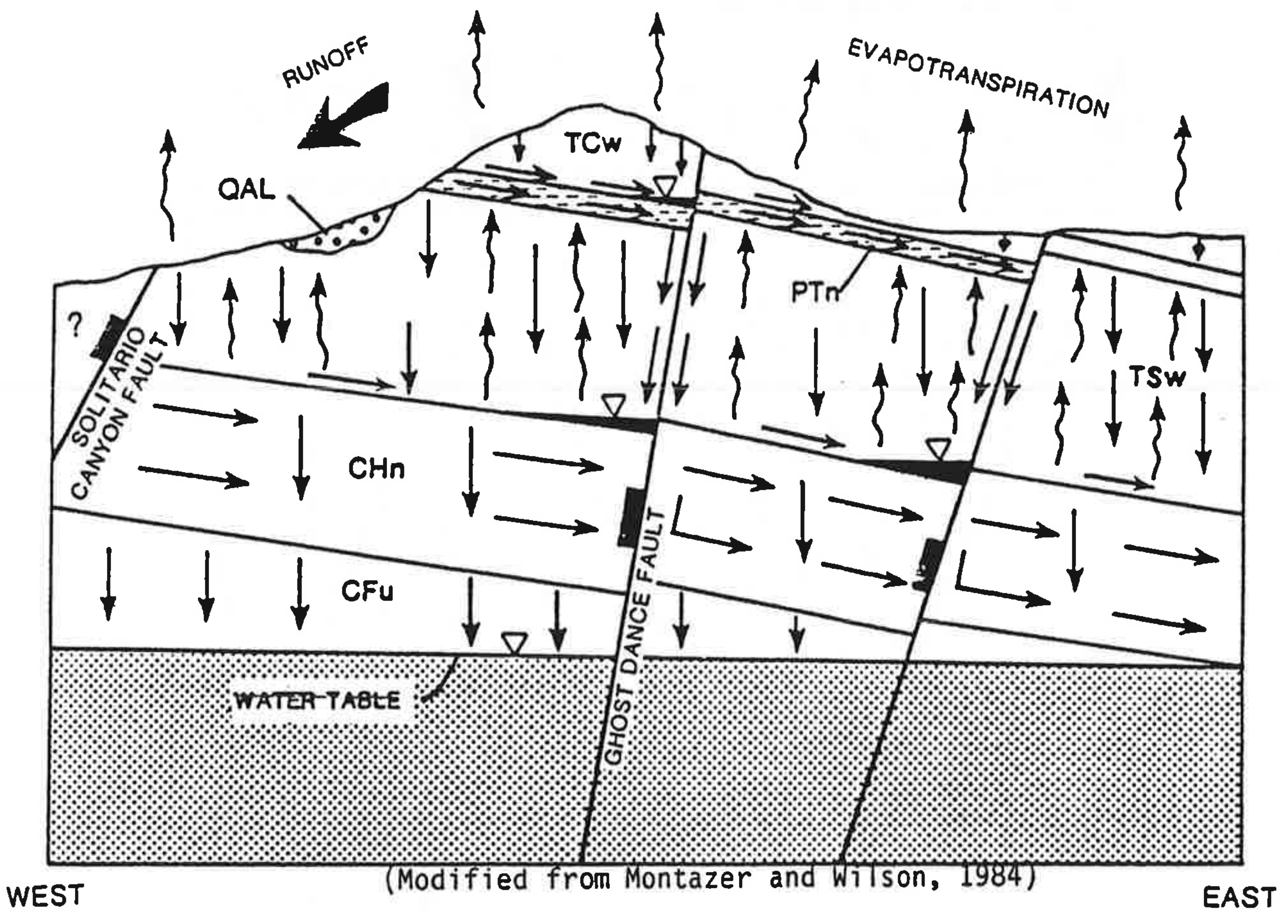
Line of Section along Broken Limb Ridge.

CARTOON OF THE HORSE-TAILING NATURE OF THE GHOST DANCE FAULT AT UZ-7A



VERTICAL AXIS NOT TO SCALE

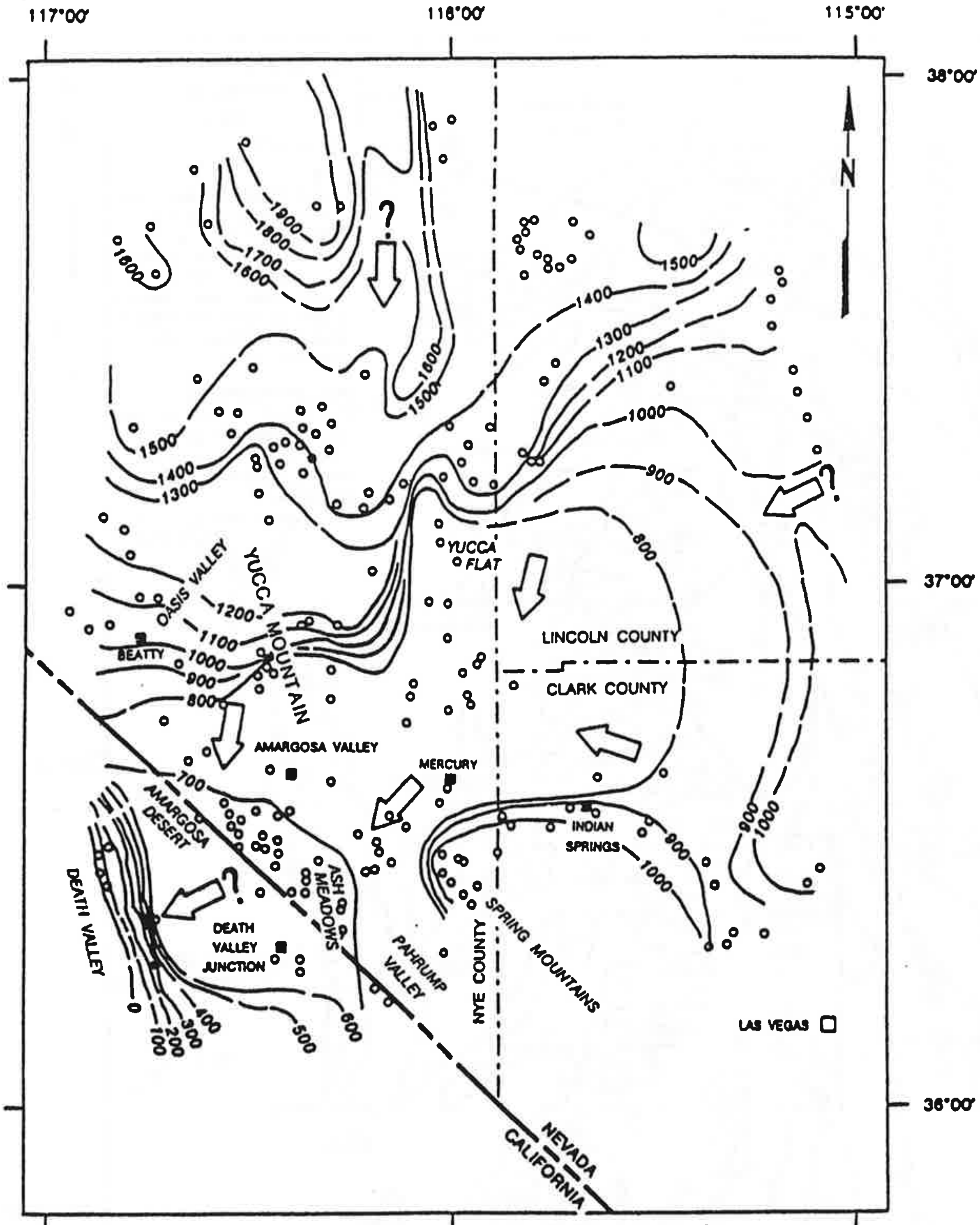
INFORMATIONAL PURPOSES ONLY



(Modified from Montazer and Wilson, 1984)

QAL	ALLUVIUM
TCw	TIVA CANYON WELDED UNIT
PTn	PAINTBRUSH NONWELDED UNIT
TSw	TOPOPAH SPRING WELDED UNIT
CHn	CALICO HILLS NONWELDED UNIT
CFu	CRATER FLATS (Undifferentiated) UNIT

LIQUID-WATER FLOW
WATER-VAPOR FLOW
NORMAL FAULT
WATER TABLE
POSSIBLE PERCHED-WATER ZONE
SATURATED ZONE
? UNIT UNCERTAIN



KEY TO SYMBOLS

0 10 20 MILES

0 10 20 30 40 KILOMETERS

—1200— — LINE OF EQUAL POTENTIOMETRIC LEVEL, IN METERS ABOVE SEA LEVEL. DASHED WHERE INFERRED. CONTOUR INTERVAL 100 M.

⇦ DIRECTION OF GENERAL GROUND-WATER FLOW (QUESTION MARK INDICATES UNCERTAINTY)

o POTENTIOMETRIC-LEVEL CONTROL POINT (WELL OF SPRING) (NOT ALL CONTROL POINTS SHOWN DUE TO SCALE LIMITATIONS)

Figure 3-10. Regional ground-water flow paths. Modified from Waddell et al. (1984).

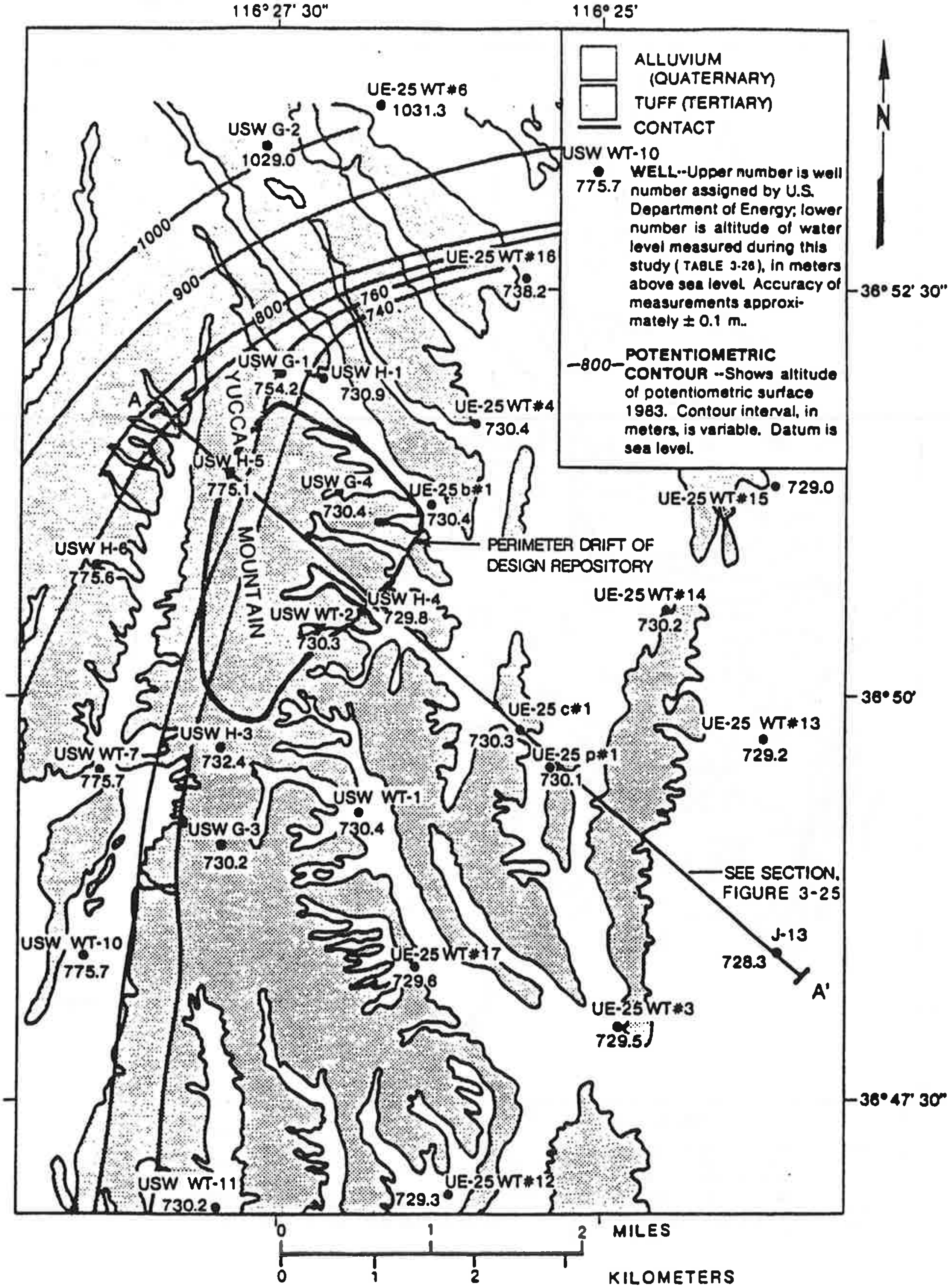


Figure 3-28. Preliminary composite potentiometric-surface map of the saturated zone. Yucca Mountain Modified from Robison (1986)

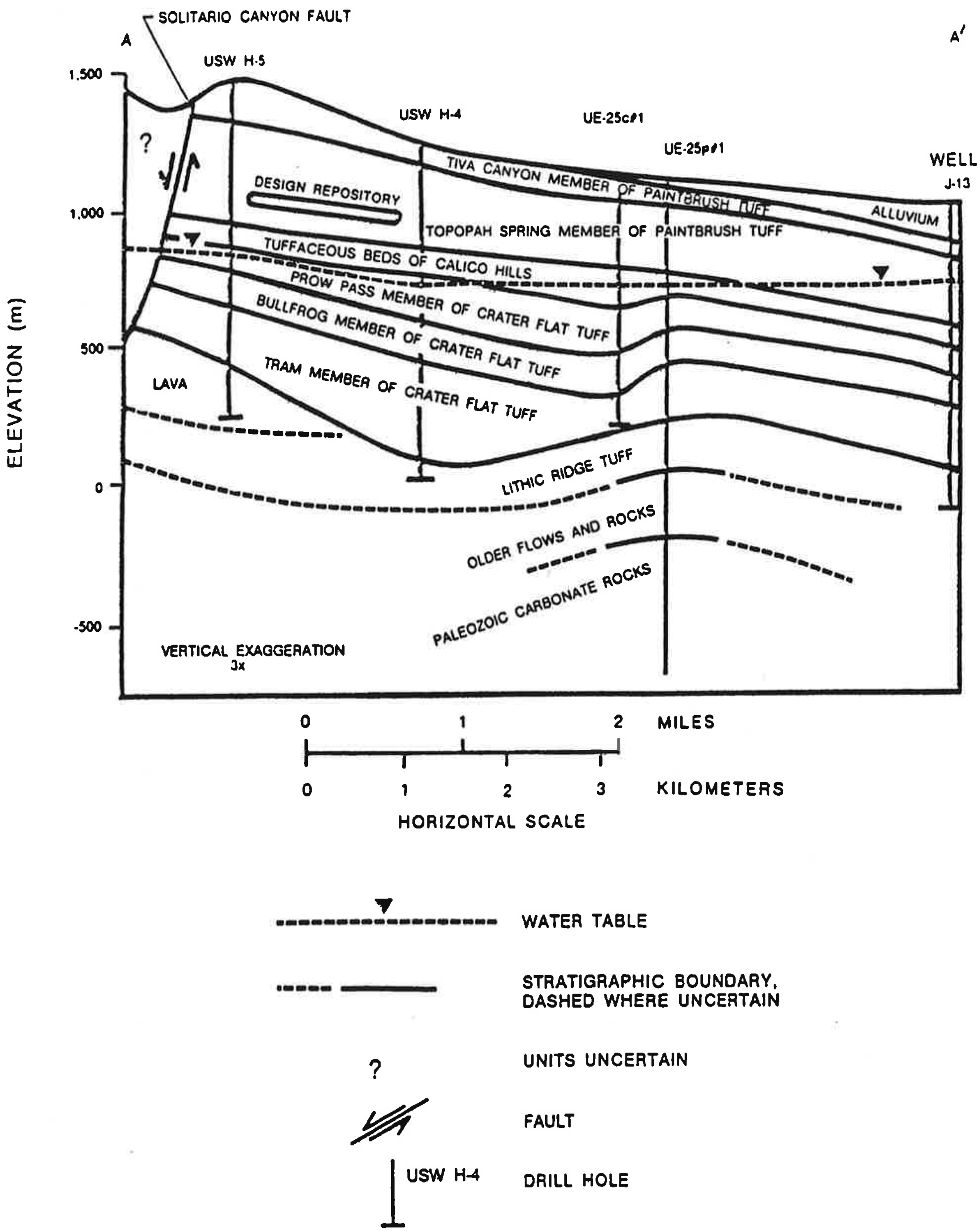


Figure 3-25. Simplified stratigraphy of section across Yucca Mountain showing stratigraphic relationships (see Figure 3-28 for location of section).