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Nevada Test Site Field Trip Guidebook 1984

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PREFACE

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, aboveground 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 geologic support groups from the Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratories, and the USGS. A good geologic understanding of the stratigraphy, structure, geochemistry, and physical properties of the rocks is essential for adequate 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. Since 1978, the massive ash-flow tuff beds under Yucca Mountain have been intensively studied to determine their potential as a radioactive waste repository. These investigations involved volcanic and earthquake hazard studies, detailed geochemical studies of compositional zonation in ash-flow tuffs, and studies of secondary mineralization.

The rock sequence at NTS is composed of upper Precambrian and Paleozoic rocks which were complexly deformed by Mesozoic compressional tectonism. Tertiary and Quaternary volcanic and clastic rocks 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-Oasis Valley caldera complex located in the western part of NTS. 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.

NEVADA TEST SITE FIELD TRIP GUIDEBOOK 1984

Compiled by

Holly A. Dockery, F. M. Byers, Jr., and Paul P. Orkild, trip leaders, with contributions from Harley Barnes, David E. Broxton, W. J. Carr, Bruce M. Crowe, Ward L. Hawkins, Evan C. Jenkins, Donathon J. Krier, Schon S. Levy, F. G. Poole, Robert B. Scott, Ralph R. Shroba, Martha G. Van De Werken, David T. Vaniman, Richard Waddell, and Richard G. Warren

ABSTRACT

The Nevada Test Site (NTS), located in southern Nevada, was established in 1950 as an area for testing nuclear devices. Various geologic studies performed in conjunction with these activities as well as recent work on a proposed radioactive waste repository are reported in detail in this guidebook and include studies on the structure, stratigraphy, geochemistry, and physical properties of the rocks at NTS.

The oldest sequence of rocks exposed in the NTS region is comprised of late Precambrian to Permian miogeoclinal rocks which were subsequently deformed during Jura-Cretaceous contraction, probably related to the Sevier orogeny. These rocks were then locally intruded by late Mesozoic (∿93 m.y.BP) plutonic rocks related to the Sierra Nevada batholith. A soil horizon mantling the older rocks occurs in portions of Frenchman and Yucca basins as well as in some of the upthrown blocks bordering the basins.

Voluminous calcalkaline ash-flow tuffs and associated volcanic rocks originating from the Timber Mountain-Oasis Valley caldera complex were extruded over much of NTS and adjacent areas from ∿16 to 10 m.y.BP. Peralkaline rocks intercalated in the volcanic sequence issued from both Silent Canyon (15-13 m.y.BP) and Black Mountain (9-7 m.y.BP) volcanic centers. These ash-flow units are characterized by interflow as well as intraflow mineral zonations. Some restricted occurrences of older ash-flow tuff units and tuffaceous sedimentary rocks (approximately 30-16 m.y.BP) are also found; however, they do not appear to be associated with the major volcanic centers cited above.

The youngest igneous rocks at NTS are composed of basaltic rocks, primarily hawaiite, the older of which are associated with the evolving silicic volcanic centers and the younger associated with Cenozoic regional extension. Late Tertiary to Recent alluvium derived from the ranges form large, coalescing fans which fill the basins with sediments and reach thicknesses of over 1 km.

Regional crustal extension, initiated possibly as long as 30 m.y.BP and continuing to the present, has produced numerous basin-range style normal faults as well as a few prominent strike-slip faults in this area. Displacement along these faults was concurrent with deposition of volcanics as old as ~14 m.y.BP, although most of the development of the basins appears to be very recent (<3 m.y.BP). Continuous clockwise rotation of the least principal stress has strongly influenced orientaton of some of the faults and their relative amounts of movement.

The geologic studies conducted at NTS have thus been valuable in two ways. First, they solve the immediate problems at hand such as determining the viability of an area for radioactive waste storage, studies of physical properties of certain testing media as occurred during formation of Sedan Crater, and hydrologic transport of radioactive nuclides traced in Frenchman Flat. Second, the synthesis of this vast body of data has done much to further the general understanding of the development of this portion of the Basin and Range Province.

ROAD LOG

DAY 1

GENERALIZED STRUCTURAL GEOLOGY FROM LAS VEGAS TO MERCURY

The Las Vegas Valley shear zone, one of the major structural features of the Basin and Range physiographic province, is reflected topographically by the northwest-trending Las Vegas Valley (Fig. 1). The Spring Mountains, culminating in Charleston Peak (3633 m), parallel Las Vegas Valley on the southwest, whereas several smaller northerly trending ranges have southerly terminations on the northeast side of the valley. The sharp westerly bending or "drag" into the Las Vegas Valley shear zone of major northerly structural and topographic trends (indicated by ranges on the northeast side of Las Vegas Valley) and offset of Paleozoic facies markers (Stewart, 1967) and major thrust faults on either side of the valley (Burchfiel, 1964) indicate right-lateral movement along the zone. Studies of stratigraphic and structural evidence indicate an aggregate right-lateral offset of 60-75 km occurring between about 17 to 11 m.y.BP (Longwell, 1974). The absolute amount of strike-slip movement along the shear zone cannot be determined, in part due to alluvial cover, but estimates range from 27 to 30 km (Fleck, 1970). The rest of the offset is attributed to structural bending or "drag."

The area traversed on this field trip lies in a belt of extensive thrust faults that occur along the east side of the Cordilleran miogeocline. These thrust faults are of Mesozoic age and occur in the hinterland of the Sevier orogenic belt. U.S. Highway 95 follows the valley for about 90 km from Las Vegas to the vicinity of Mercury, Nevada (Fig. 1).

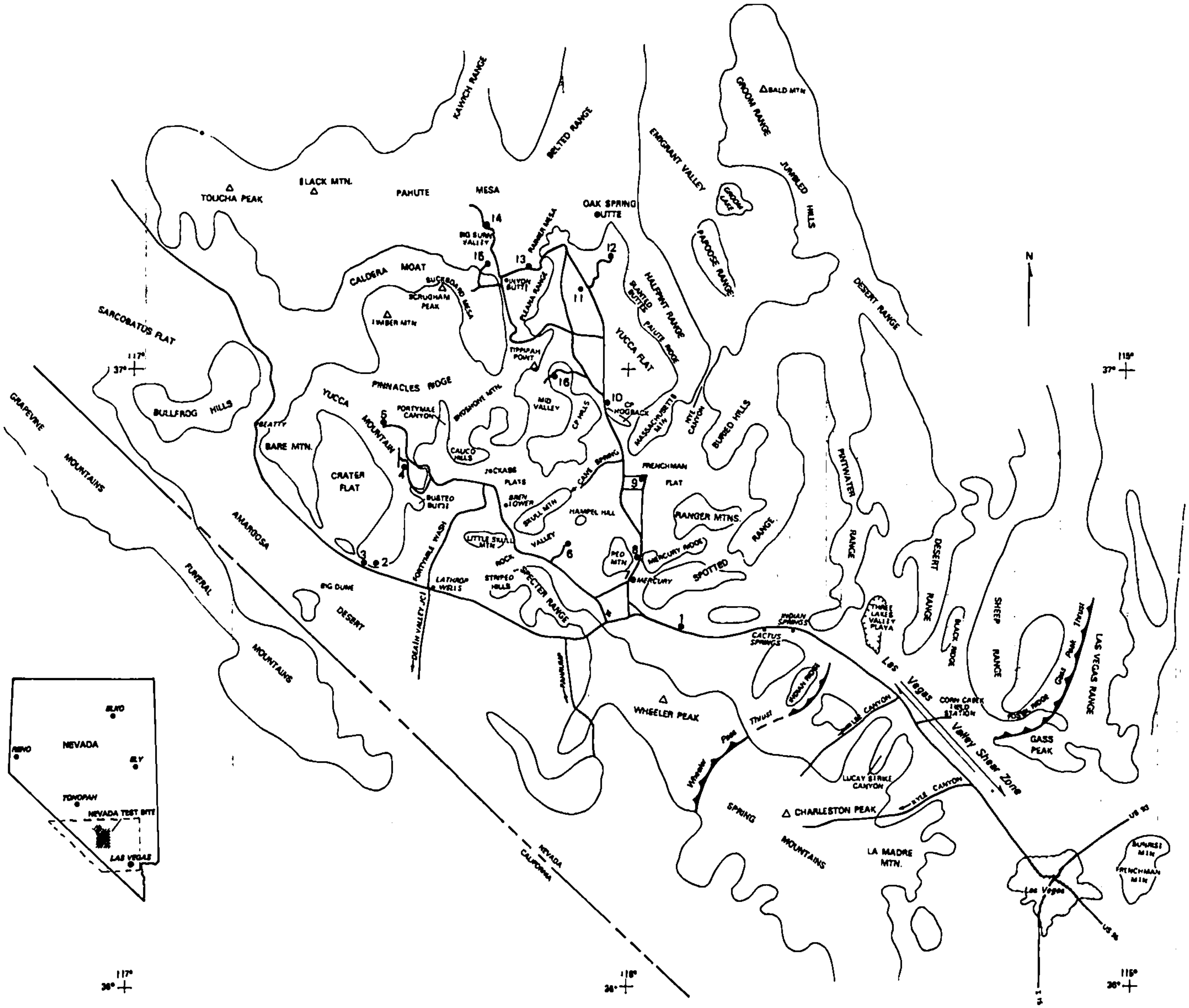

Fig. 1.

Southern Nevada region showing principal geographic features, probable offset of Wheeler Pass Thrust and coeval Gass Peak Thrust, and numbered stops on NTS Field Trip.

Cumulative Mileage	
0.0	Las Vegas, intersection of Interstate 15 and U.S. 95. Proceed north on U.S. 95.
2.7	Decatur Blvd. overpass.
9.1	Craig Road turnoff. Potosi Mountain at 8:30 o'clock is capped by Monte Cristo Limestone of Mississippian age. Prominent ridge between 8:00 and 9:00 is capped by Permian Kaibab Limestone. Wilson Cliffs between 8:30 and 9:30, composed of buff and red Aztec Sandstone of Triassic(?) and Jurassic age, form the lower plate overridden by Keystone thrust. Narrow ridge at 9:30 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 9:30 and 11:00 are exposed carbonate rocks of Cambrian, Ordovician, Silurian(?), Devonian, Mississippian, Pennsylvanian, and Permian age. On Sheep Range at 1:00, the outcrops are rocks of Cambrian through Mississippian age. On Las Vegas Range between 1:00 and 3:00 most outcrops are the Bird Spring Formation of Pennsylvanian and Permian age. Muddy Mountains at 4:00. Sunrise and Frenchman Mountains between 4:30 and 5:30.
14.8	View of La Madre Mountain stratigraphy between 9:00 and 10:00. Lower thin black band is dolomite of Devonian age (probably Ironside Dolomite 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 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.
16.1	Charleston Park Road - Kyle Canyon turnoff (Nevada State Highway 39).
19.4	Rest area on right ... continue straight ahead. A few of the geologic features exposed in the next few miles near the Lee Canyon Road (Nevada State Highway 52) are outlined on Fig. 1. The offset of the Wheeler Pass and Gass Peak thrusts is commonly cited in support of right-lateral movement along the shear zone. The contrast in rock facies and thicknesses on opposite sides of the valley offers corroborative evidence of strike-slip movement. To the northeast: The rocks of the Sheep Range between 2:00 and 3:00 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 Pogonip Group carbonate rocks, 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. 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 Test Site.

To the southwest: The ridge east of Lucky Strike Canyon consists of a much thinner section than in the Sheep Range and contains several different lithofacies. At 10:00 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 Dolomite 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 11:00 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 9:30 is the upper part of the Nopah Formation.

Fossil Ridge at 4:00 is composed of Cambrian and Ordovician rocks. Gass Peak thrust (Fig. 1) at 4:30 separates upper plate of Cambrian rocks on left from lower plate of Pennsylvanian and Permian rocks of the Las Vegas Range on the right.

25.3 Lucky Strike Canyon Road to left. Road to right leads to Corn Creek Springs Field Station of U.S. Fish and Wildlife Service, which manages the Desert Game Range. Continue straight ahead.

26.0 Badland topography at 3:00 developed on Las Vegas Formation. Near Las Vegas, similar yellowish-gray fine-grained beds have yielded fossil mollusks and mammals of Pleistocene age.

29.5 Lee Canyon turnoff. Nevada 52 on left .... continue straight ahead. At 9:00 on skyline is Charleston Peak, elevation 3633 m. Black Ridge at 3:00 is composed of Cambrian and Ordovician strata. Desert Range at 2:00 is composed of Cambrian to Devonian strata.

33.0 Playa of Three Lakes Valley at 2:00. Pintwater Range at 1:00 is composed of Cambrian to Devonian strata. Indian Ridge at 10:30 is composed of Cambrian and Ordovician rocks. Ridge between 8:00 and 10:00 is composed of Bird Spring Formation. The Wheeler Pass thrust probably separates these two ridges.

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

39.0 Southwest end of Pintwater Range between 1:00 and 3:00 is composed of Ordovician, Silurian, and Devonian rocks. Ridge at 10:00 consists of gray cliffs of Monte Cristo Limestone and alternating brown silty-sandy limestone and gray limestone of the Bird Spring

Formation. Prominent high point on skyline ridge at 9:30 is Wheeler Peak.

41.0 Light-gray outcrop, at 3:00, is mostly Devonian carbonate rocks. Near this point, the trend of Las Vegas Valley changes from northwest to west-southwest past Indian Springs, reflecting either a bend in the Las Vegas Valley shear zone or the presence of a conjugate northeast-trending fault.

42.1 Village of Indian Springs. Indian Springs Valley is at 3:00. White and brown outcrops in distance at 1:00 are Eureka Quartzite. Dark dolomite on ridge at 12:30 is Upper Cambrian Nopah Formation. Gray and brown outcrops forming prominent ridge south of town, 9:00 to 11:00, are Bird Spring Formation.

45.4 Village of Cactus Springs. Prominent black and white banded dolomite on ridge between 1:00 and 3:00 is upper part of Nopah Formation.

47.7 Prominent ridge on skyline between 9:00 and 12:00 is northwest end of Spring Mountains; Wheeler Peak at 9:30, Mount Stirling at 10:30.

49.5 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 million years of approximately 5 m/km.

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

55.1 STOP 1: View of Paleozoic units in the Spotted Range between 12:00 and 4:00. 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 Sheep Range 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, 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 1:30 is overlain by black dolomite of the lower member of the Ely Springs. Ridge on skyline between 12:30 and 2:30 is South Ridge capped by Devils Gate Limestone. Nevada-Devils Gate contact is on skyline at 1:30. Prominent black band with brownish slope-former below is the

TABLE I

PRE-CENOZOIC ROCKS EXPOSED IN AND NEAR YUCCA FLAT, NEVADA TEST SITE
(modified from Orkild, 1982)

Age	Formation	Approximate Thickness (m)	Dominant Lithology (m)	
Permian (?) and Pennsylvanian	Tippipah Limestone	1100	limestone	Upper carbonate (1100)
Mississippian and Devonian	Eleana Formation	2320	argillite, quartzite	Upper clastic (2320)
Devonian	Devils Gate Limestone	420	limestone	
	Nevada Formation	465	dolomite	
Devonian and Silurian	Dolomite of Spotted Range	430	dolomite	
Ordovician	Ely Springs Dolomite	93	dolomite	Lower carbonate (4700)
	Eureka Quartzite	104	quartzite	
	Antelope Valley Limestone	466	limestone	
	Ninemile Formation	102	siltstone	
	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 (2900)
	Stirling Quartzite	915	quartzite	
Precambrian	Johnnie Formation (base not exposed)	915	quartzite, limestone, dolomite	
TOTAL THICKNESS		11,000 +		

lower part of the Nevada Formation and can best be seen in middle part of range between 2:00 and 2:30.

58.7 Low ridges in foreground between 10:30 and 2:30 are Ordovician Antelope Valley Limestone. Ridge on skyline between 11:00 and 1:00 consists of Eureka Quartzite through Devils Gate Limestone.

59.3 Massive gray cliffs at 3:00 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).

59.5 Highway bends to more westerly direction. Hills on skyline between 12:00 and 1:00 are Specter Range. Skull Mountain in distance at 2:00 is composed of silicic volcanic rocks, capped by black basalt flows. Mercury camp at 4:00. Mercury Valley to northwest is the last 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.

60.8 Mercury interchange. (Mercury camp 4:00).

63.1 Army #2 well site on right.

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

66.6 Telephone relay station on right. Bonanza King Formation at 3:00, Nopah Formation at 9:00.

67.5 On right, large fault brings Cambrian Bonanza King down against uppermost Precambrian and Lower Cambrian Wood Canyon Formation.

68.5 On right, contact between Upper Precambrian Stirling Quartzite and Wood Canyon Formation.

69.1 On left, Miocene and Pliocene gravels contain at their base ash-fall tuff layers correlative with those at the base of the upper Miocene Paintbrush Tuff (Table II), whose source is near the western edge of NTS, 56 km to the northwest. Unconformably beneath the ash beds are steeply tilted upper Miocene tuffaceous sediments.

69.8 Intersection of U.S. 95 and road to Pahrump. On skyline at 11:00 are the Funeral Mountains.

70.8 Light-gray hills at 3:00 are highly faulted Antelope Valley Limestone.

74.8 Low pass through Silurian Lone Mountain Dolomite on right and Nopah Formation on left.

75.3 To right, exposure of Ely Springs at 2:30-3:30 (dark band), underlain by Eureka Quartzite just above valley fill and overlain by undifferentiated Silurian dolomite. Amargosa Desert to left.

79.3 Low hills of Stirling Quartzite to right and left of highway. At 1:00 low hills of Carrara and Wood Canyon Formations.

80.3 Bonanza King Formation outcrops to right.

80.8 Bonanza King Formation exposures on left.

82.0 Rock Valley Wash.

TABLE II

PRINCIPAL CENOZOIC VOLCANIC AND SEDIMENTARY UNITS
(modified from Orkild, 1982 and Carr, Byers, and Orkild, in press)

FORMATION, Member	Inferred Volcanic Center	General Composition	Approximate Age (m.y.)
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 PAVITS SPRING (underlies Crater Flat Tuff)	DISPERSED	Tuffaceous sediments	14-?
HORSE SPRING FORMATION	DISPERSED	Mostly sediments	30

83.0 Fresh water limestone beds in low hills on right and left. Equivalent beds have been dated at 29.3 $\pm$ 0.9 m.y. in Frenchman Flat area. Hills at 9:00 are composed of Bonanza King Formation.

83.5 Lathrop Wells Paleozoic section (Sargent, McKay, and Burchfiel, 1970), in Striped Hills at 2:00 to 3:00, begins in Wood Canyon Formation just above the sand fan. Essentially complete Cambrian section is vertical to slightly overturned. In ascending order - Wood Canyon Formation, Zabriskie Quartzite, Carrara, Bonanza King, and Nopah Formations. The Bishop ash occurs in sandy alluvium forming large fan on south slope of hills at 3:00. The Bishop ash erupted from Long Valley caldera, approximately 235 km to the northwest about 730,000 yr ago.

84.9 Tunnels for MX experiments in Little Skull Mountain visible at 3:00.

87.1 Village of Lathrop Wells. Highway to left goes to Death Valley Junction, California, and to Death Valley via Furnace Creek Wash. At 2:00-2:30 is Yucca Mountain; on skyline behind Yucca Mountain is Pinnacles Ridge, which forms the south rim of Timber Mountain caldera (Fig. 2), discussed in detail on second day of field trip. Also visible is Fortymile Wash and the varicolored volcanic rocks of Calico Hills. Range to left in distance is Funeral Mountains, which forms the east side of Death Valley.

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

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

93.2 STOP 2: Young basalt cones and flows (Fig. 3). The Crater Flat area (Fig. 1) 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 and others (1982), Crowe and others (1982), and Crowe and others (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 (written commun., USGS 1979) and R. F. Marvin, USGS (written commun., 1980).

- o 3.7-m.y. cycle (Pb): 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. 3).
- 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. 3). From northeast to southwest, the major centers in this cycle include unnamed cone, Black, Red, and Little Cones.
- o 300,000-yr cycle (Qb): The youngest cycle is marked by essentially undissected cones and flows of the Lathrop Wells center at Stop 2.

The 300,000-yr basalt cycle at the Lathrop Wells volcanic center (Stop 2) includes a large cinder cone with two small satellite cones that overlie and are flanked to the east by aa flows (Fig. 4). Calculated magma volume is about 0.06 km^3. The satellite cones are overlapped by deposits of the main cone. The large cone, referred to as the Lathrop Wells cone, has a height/width ratio of 0.23. Scattered pyroclastic deposits from the Lathrop Wells vent are found for a distance of more than 4 km to the northwest. This alignment of pyroclastic deposits indicates a strong and consistent wind flow from the southeast during the eruption. The cone appears unmodified by erosion except for minor slumping of steep cone slopes. Two aa flows vented at several sites along the east flank of the Lathrop Wells cone. Flow vents are marked by arcuate spatter ridges

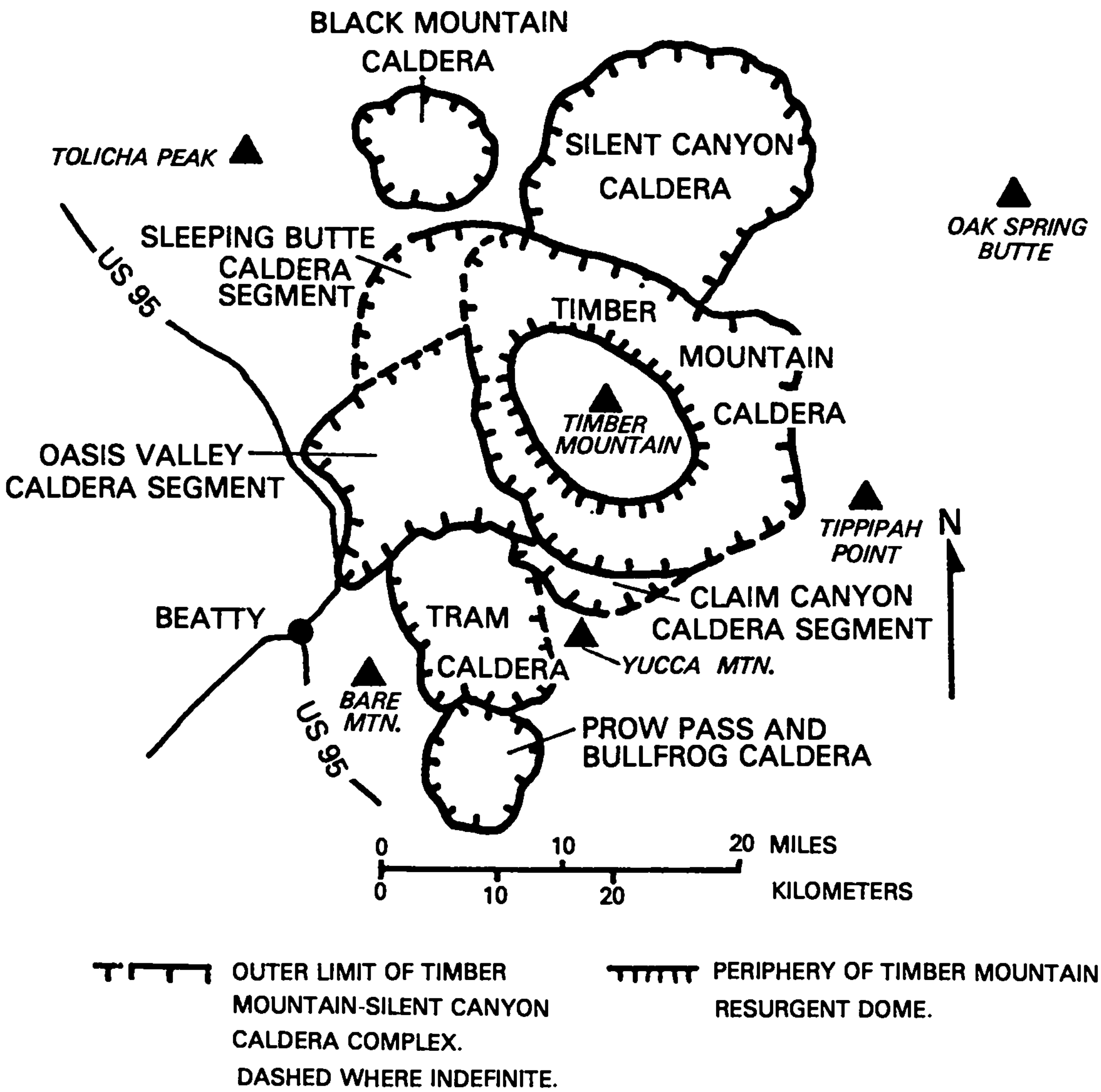

Fig. 2.
NTS region showing caldera outlines, known and inferred.

extending east and southeast of the cone. The lavas have unmodified flow margins and rubbly flow surfaces consistent with their young age. They are locally covered by loess and eolian sands. The probable oldest deposits of the Lathrop Wells cone are well-bedded pyroclastic (base) surge deposits (Fig. 5) that are exposed only on the northwest side of the cone where they overlap a topographic ridge upheld by welded tuff. They probably underlie the scoria deposits of the cone and thus record an episode of phreatomagmatic activity during the early eruptive stages of the center.

The ages of the Quaternary alluvial deposits are consistent with ages on the basalt. Before eruptions, alluvium of middle Pleistocene age locally developed a dense K-horizon that gave a uranium series age of about 345,000 yr (Fig. 5). The pyroclastic material became incorporated locally in upper Pleistocene alluvium (Fig. 5),

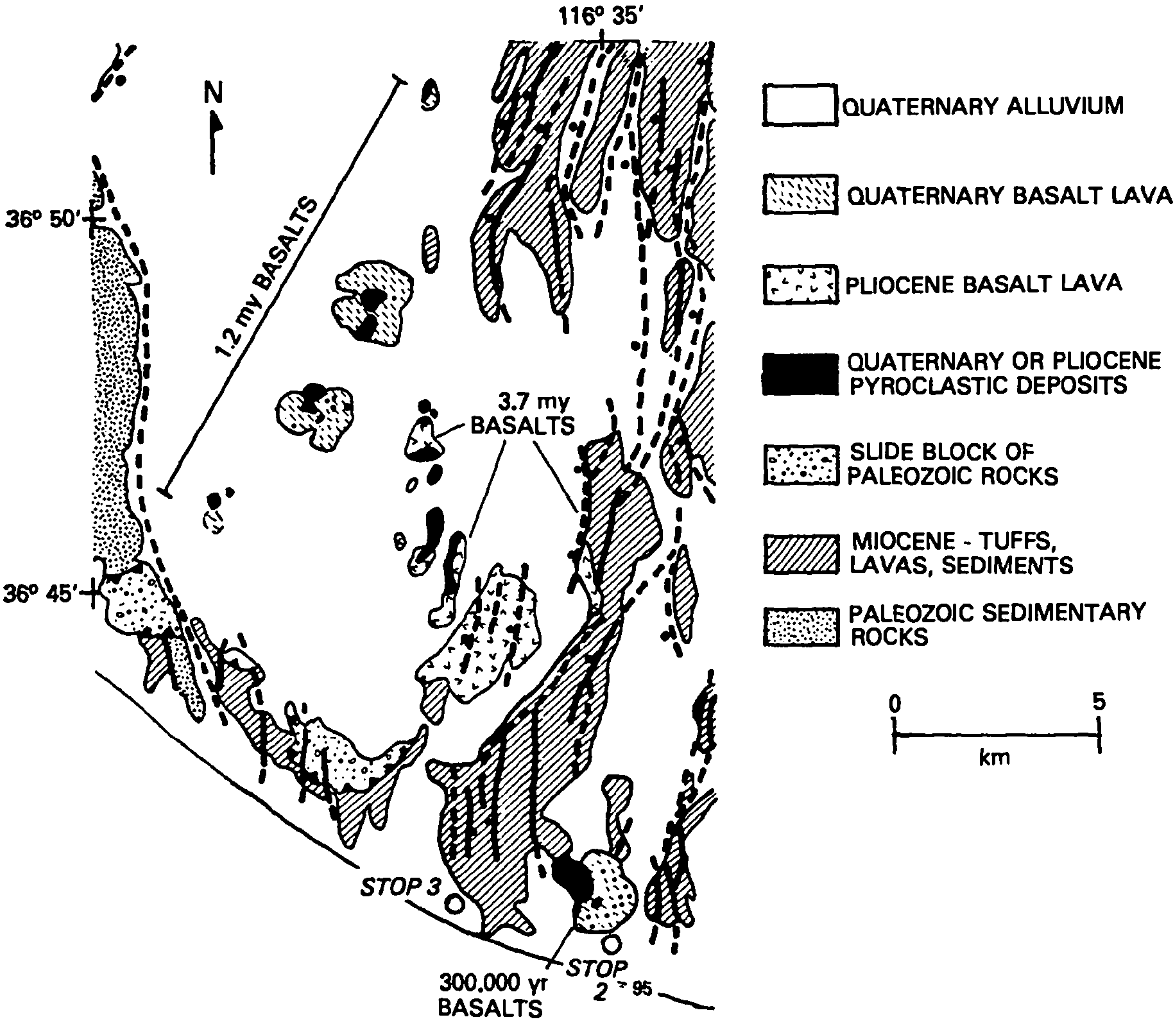

Fig. 3.
Southern Crater Flat area showing basalt centers and Stops 2 and 3 (modified from Crowe and Carr, 1980).

and a loessial silt deposit accumulated on the cinder cone and regionally on the Q2 alluvium before about 25,000 yr ago.

The structural controls for the location of the center are not obvious. The cone, summit crater, and the satellite cones 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 (Figs. 3 and 6); faults west of this lineament have a more northerly trend. It is suggested that the strike of the faults influenced the location of the center; that is, the eruptions were fed from dikes whose trends were controlled by the regional stress field, i.e., least compressive stress direction.

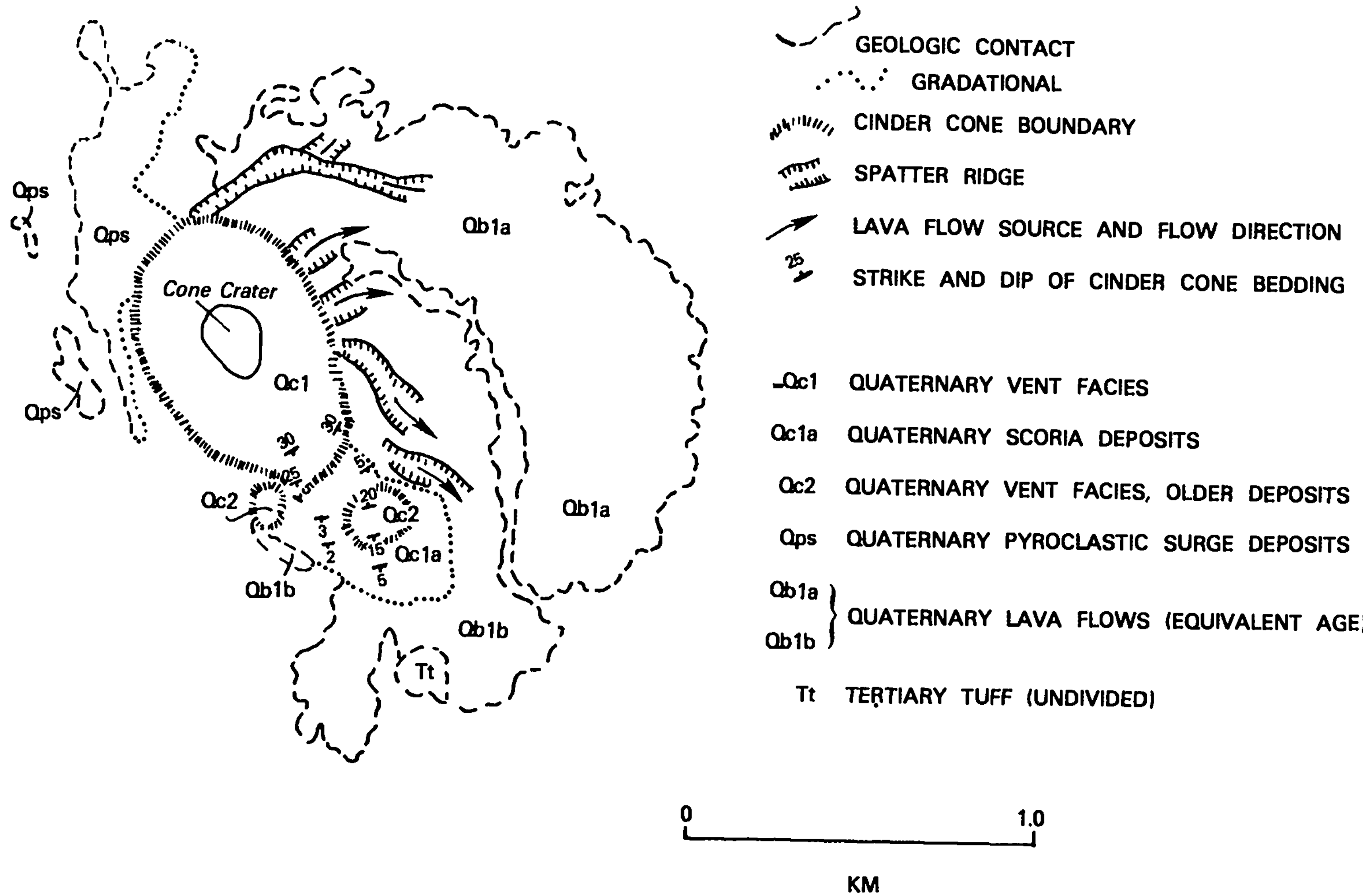

Fig. 4.
Geologic map of Lathrop Wells volcanic center (Stop 2).

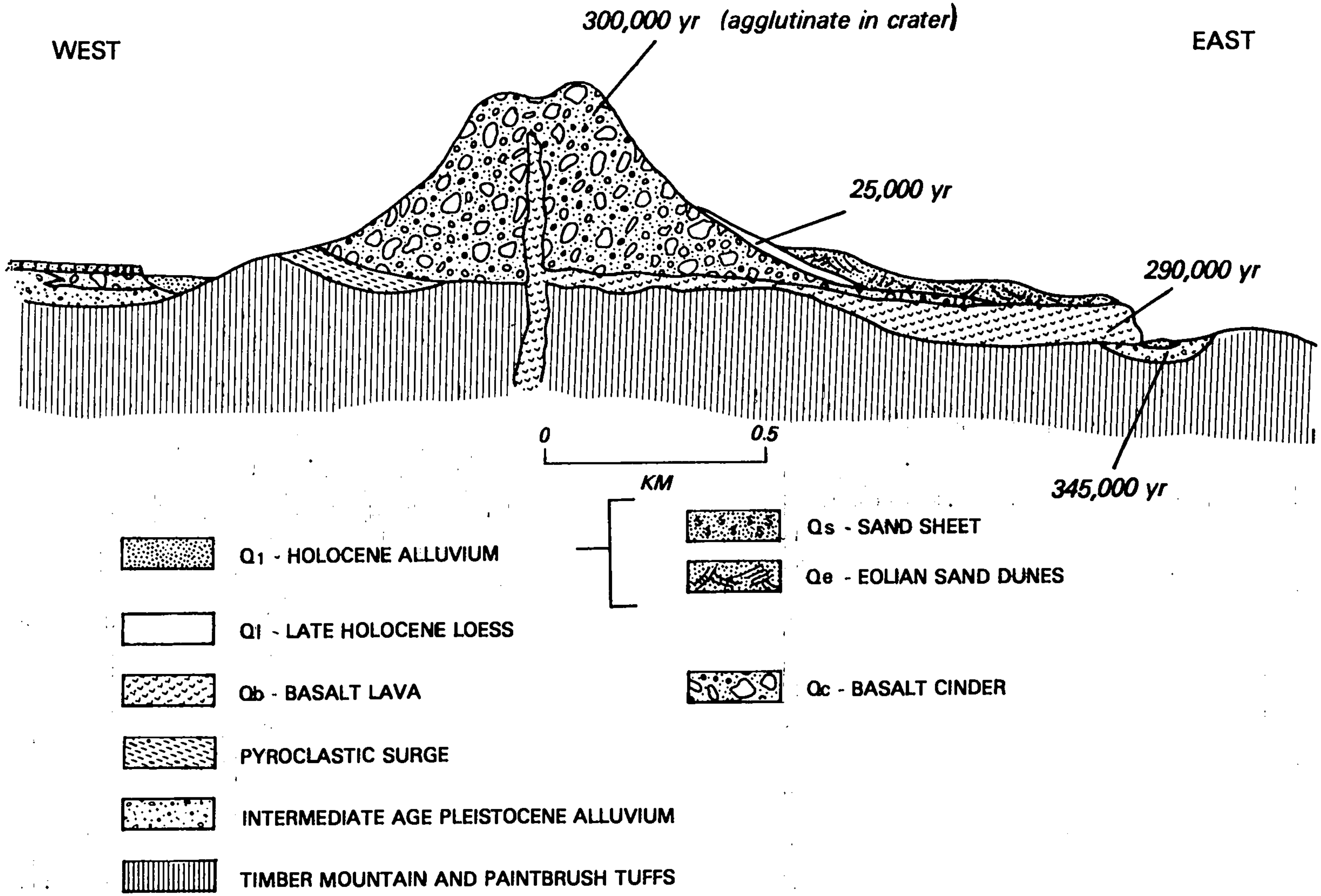

Fig. 5.
Sketch of geologic relations at Lathrop Wells volcanic center (Stop 2).

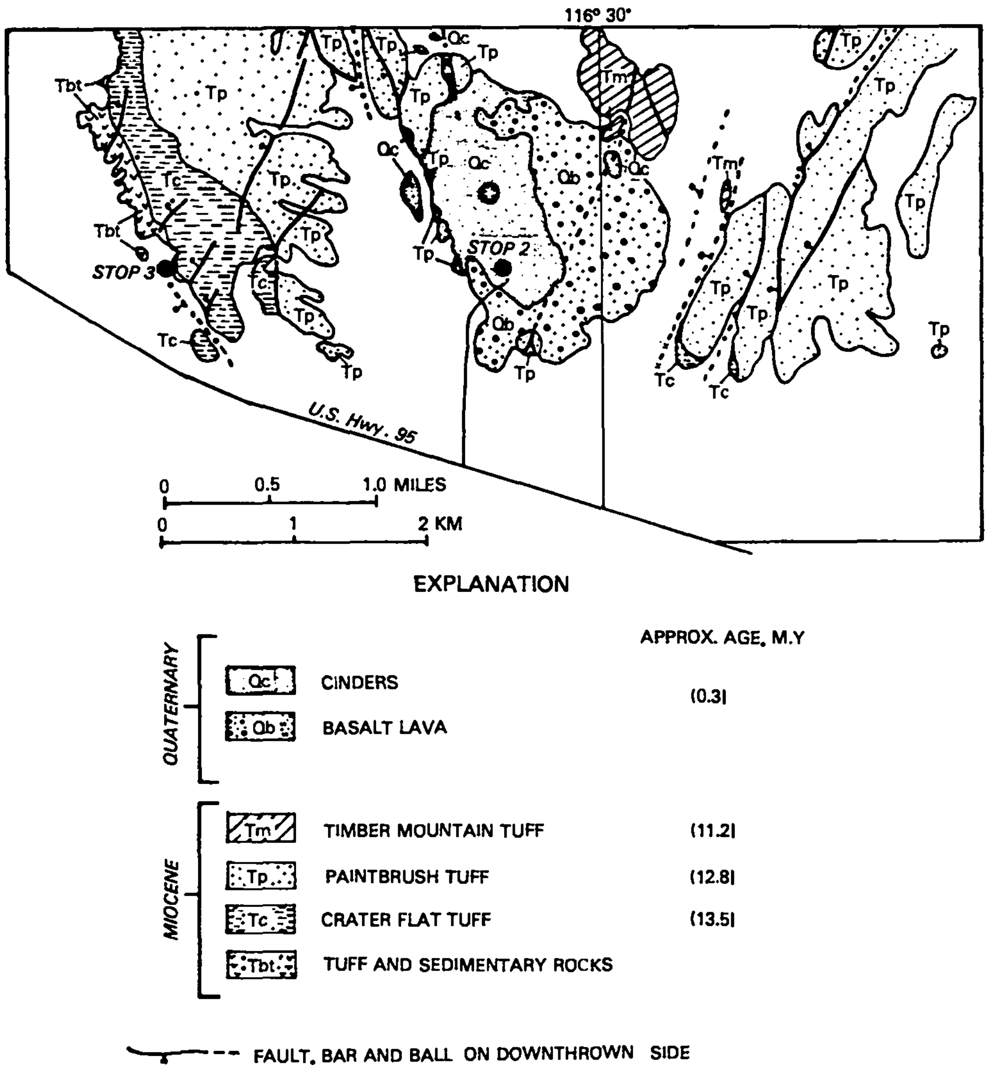

Fig. 6.
Generalized geologic map of type section area of Crater Flat Tuff (Stop 3).

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. 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 probe. Groundmass 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 and others (1982).

Lavas of the Lathrop Wells center have been dated at about 300,000 yr, consistent with the lack of erosional modification of both cones and flows. The basalts are normally magnetized and thus assigned to the Brunhes Normal Magnetic Epoch. The three K-Ar dates are 300,000 yr for agglutinate in the summit crater, 290,000 yr for the lava, and 230,000 yr on a bomb (Fig. 5) collected near the base of the cinder cone. We believe the age on the bomb is probably the least reliable age because of its discordance with the older ages, which are in close agreement.

95.6 STOP 3: Miocene volcanic units and type section of the Crater Flat Tuff (Fig. 6). Stop at Amargosa Farm Area sign on right side of road. Hike to hills about 0.5 miles to north. 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, although the Tram Member, the oldest unit, is missing here.

The Crater Flat Tuff is a sequence of three compositionally similar calcalkaline rhyolitic ash-flow tuffs characterized by subequal modal plagioclase, sanidine, and quartz with minor biotite and hornblende or orthopyroxene (Byers and others, 1976b; Byers and others, 1983; Carr and others, 1984, in press). Four K-Ar dates of 14.1 to 12.9 m.y., averaging 13.5 m.y., were obtained on biotites from specimens in the basal vitrophyre of the Bullfrog Member (Marvin and others, 1970, their Table II). The source areas for the Crater Flat Tuff are obscured by later volcanism, tectonism, and alluviation. Carr (1982; Carr and others, 1984, in press) suggests that the Tram Member was erupted from a cauldron partly buried by upper Tertiary alluvium in the northern part of Crater Flat, and that the overlying Bullfrog and Prow Pass Members were erupted from a buried cauldron in central Crater Flat (Fig. 2). Warren (1983a, 1983b) has recently correlated the Bullfrog and Prow Pass Members with parts of the tuffs of Area 20 beneath Pahute Mesa.

Although the basal Tram Member of the Crater Flat Tuff is missing here, the Bullfrog Member is underlain by a thick sequence of bedded air-fall tuffs and reworked volcaniclastic sediments. An extensive deposit within the bedded tuffs contains large clasts of the Tram Member and densely welded peralkaline Grouse Canyon Member of Belted Range Tuff. The Bullfrog Member, outside the cauldron, at this location is a simple cooling unit about 100 m thick. The base of the member consists of nonwelded, vitric ash flows. These grade upward into a vitrophyre about 6 m thick from which the K-Ar age samples were taken. The thick interior of the member is moderately welded and thoroughly devitrified. It contains rare to sparse xenoliths, a few of which are greenish aphyric welded tuff, which may be peralkaline Grouse Canyon. The uppermost portion of the Bullfrog Member is partially welded vitric tuff.

Lenticular masses of monolithologic breccia of welded tuff rest on an irregular surface on the upper part of the Bullfrog Member. The monolithologic breccia is poorly sorted and consists of clasts of welded Bullfrog Member as much as a meter in diameter.

A thin air-fall tuff less than a meter thick marks the base of the Prow Pass Member. The Prow Pass is a simple cooling unit less than 50 m thick, having a nonwelded vitric basal zone, a partially welded devitrified interior, and a nonwelded vitric upper zone.

The Prow Pass is overlain by several meters of bedded tuff and by the Topopah Spring and Tiva Canyon Members of the Paintbrush Tuff.

After stop, turn around and return east on U.S. 95.

103.9 Turn left on road to Lathrop Wells guard gate of the NTS.

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

109.9 At approximately 3:00 view Little Skull Mountain, capped by Miocene (approximately 10 m.y. R. F. Marvin, USGS written commun., 1980) 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 is Yucca Mountain.

113.8 Low hills at 10:00 are Topopah Spring Member capped by 9.6 m.y.-old basalt (R. F. Marvin, USGS written commun., 1980) of [Engine Maintenance and Disassembly (EMAD)].

115.2 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.

117.4 Turn left onto road next to the Nevada Research and Development Area (NRDA) facility (formerly Nuclear Rocket Development Station).

119.0 On skyline at 12:00 Shoshone Mountain is capped by 8.9 m.y.-yr old rhyolite lavas (R. F. Marvin, USGS written commun., 1980).

119.5 Turn left and proceed west toward Yucca Mountain.

120.1 EMAD facility to left. Originally used for nuclear rocket engine maintenance, now operated by Westinghouse for handling and temporary storage of nuclear waste.

120.7 Rocket assembly facility at 3:00, one of several built in conjunction with NRDS in 1960's.

123.7 Busted Butte at 11:00.

125.2 Road to water Well J-13. Fran Ridge in foreground to west is composed of Topopah Spring Member, overlain by light-colored bedded tuff and Tiva Canyon Member.

125.4 Crossing Fortymile Wash.

125.9 Turn left at sign for Nevada Nuclear Waste Storage Investigations (NNWSI) drill hole USW G-3. Follow geography and generalized geology on Fig. 7 to Stop 4.

128.1 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 Canyon Member. Dips range from steeply westward to overturned within a 100-m-wide zone. On the right are exposures of lithophysal cavities and north-northwest-striking fractures in Topopah Spring Member in outcrops along wash.

128.4 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 Paintbrush sequence. 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 west-dipping strata.

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

130.6 Turn left toward Yucca Crest. On either side are a series of west-dipping normal faults that displace the caprock of Tiva Canyon Member, repeating the section. At 12:00 approaching a 20° to 30° dip slope; this contrasts with Yucca Crest that dips at only 5° to 7°.

130.8 STOP 4: Park bus at drill hole WT-1 site at mouth of Abandoned Wash. Hike west about 1.5 km to road at top of Yucca Mountain; examine fault patterns and compositional and cooling zonations in the Tiva Canyon Member. The generalized map and accompanying detailed geologic section (Fig. 7) 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 drag zones. 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 tuff foliations, suggesting rotation. In addition to required rotation of the fault planes and intervening blocks, graben-like features (Fig. 7) suggest a geometric control by the shape of major normal faults. The attitude of major faults decreases from the average of 70° at the surface to 60° at depth as suggested by some drill holes. The development of tension gashes would evolve into rotated normal faults and related grabens with greater degrees of extension. 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.

GENERALIZED GEOLOGIC STRIP MAP ACROSS YUCCA MOUNTAIN

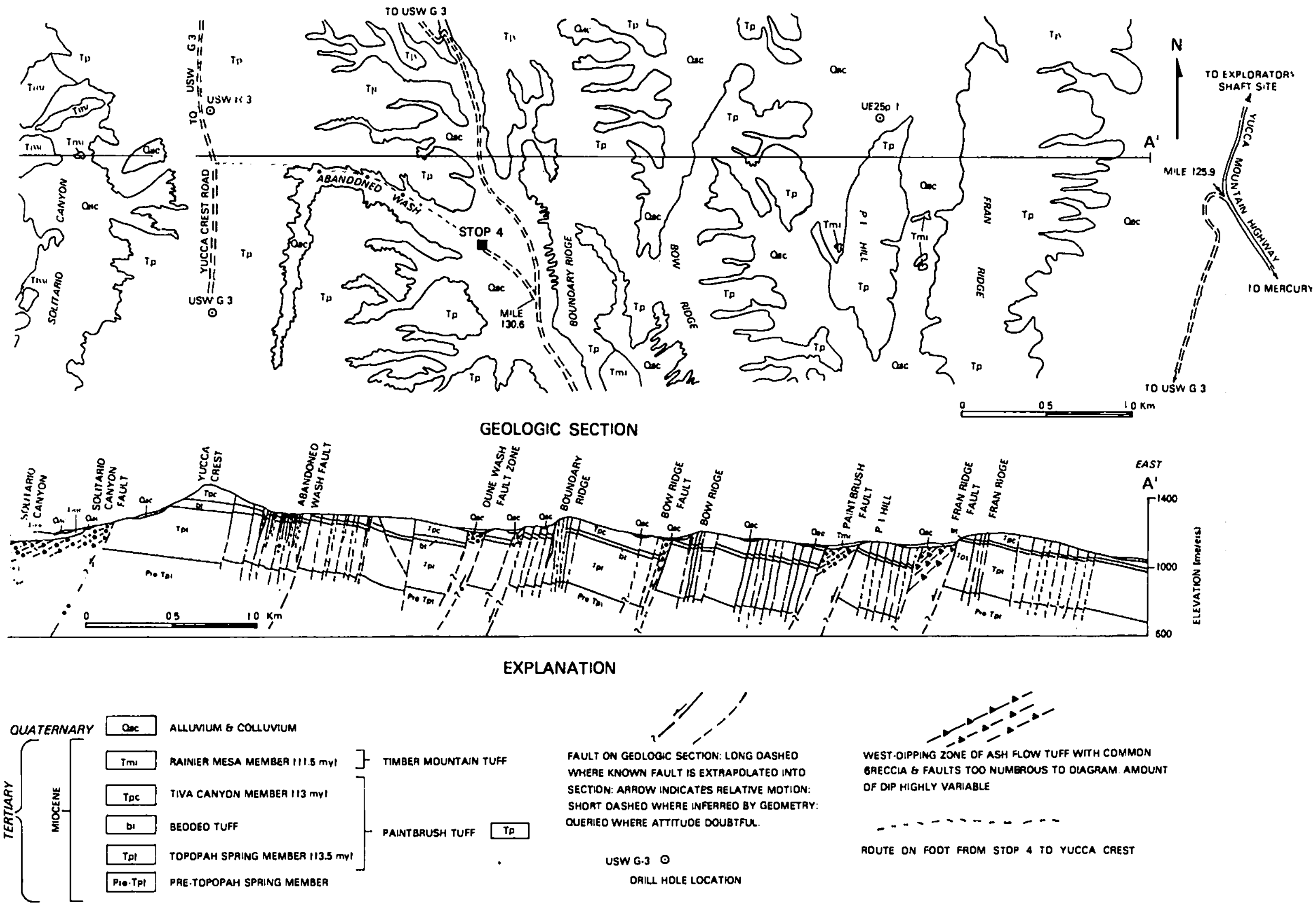

Fig. 7.
Geology of a part of the Yucca Mountain area (Stop 4).

cinder cones and basalt lavas in Crater Flat. The steep east-facing front of Bare Mountain may be a major bounding fault formed during subsidence of the caldera complex (Fig. 2) that is the probable source of the Crater Flat Tuff.

Lunch. Hike back down to bus. Turn around and retrace route to turn off for NNWSI drill hole G-3.

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

145.0 STOP 5: (Depending on time, this stop may be cancelled). Exploratory Hole USW G-4 for proposed exploratory shaft to test Topopah Spring Member as candidate host for nuclear waste repository. Turn around and retrace route back to NRDA facility.

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 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 (location B, Fig. 8).

169.6 Turn off at 5310 Road.

173.0 STOP 6: Trench RV-2 on strand of Rock Valley fault system. In 1978, two trenches were dug across one of the most prominent Quaternary strands of the Rock Valley fault system, a part of a major northeast-striking, seismically active, structural zone in the southeastern NTS area. The location of the fault scarps and trenches is shown on Fig. 8. The stop is at trench RV-2.

The trend (RV-2, Fig. 9) is cut across the scarp at a point where it is only about 1.5 m high and has a maximum slope angle of about 6°. Along most of the scarp, farther northeast, the height of the scarp, accentuated somewhat by erosion, is as much as 4 m and the slope angle is about 8°. In several drainages the scarp has been completely breached and removed by erosion east and west of the trench location.

The trench is cut mainly in Q2 alluvium, whose age is generally between about 35,000 and 750,000 yr (Hoover and others, 1981).

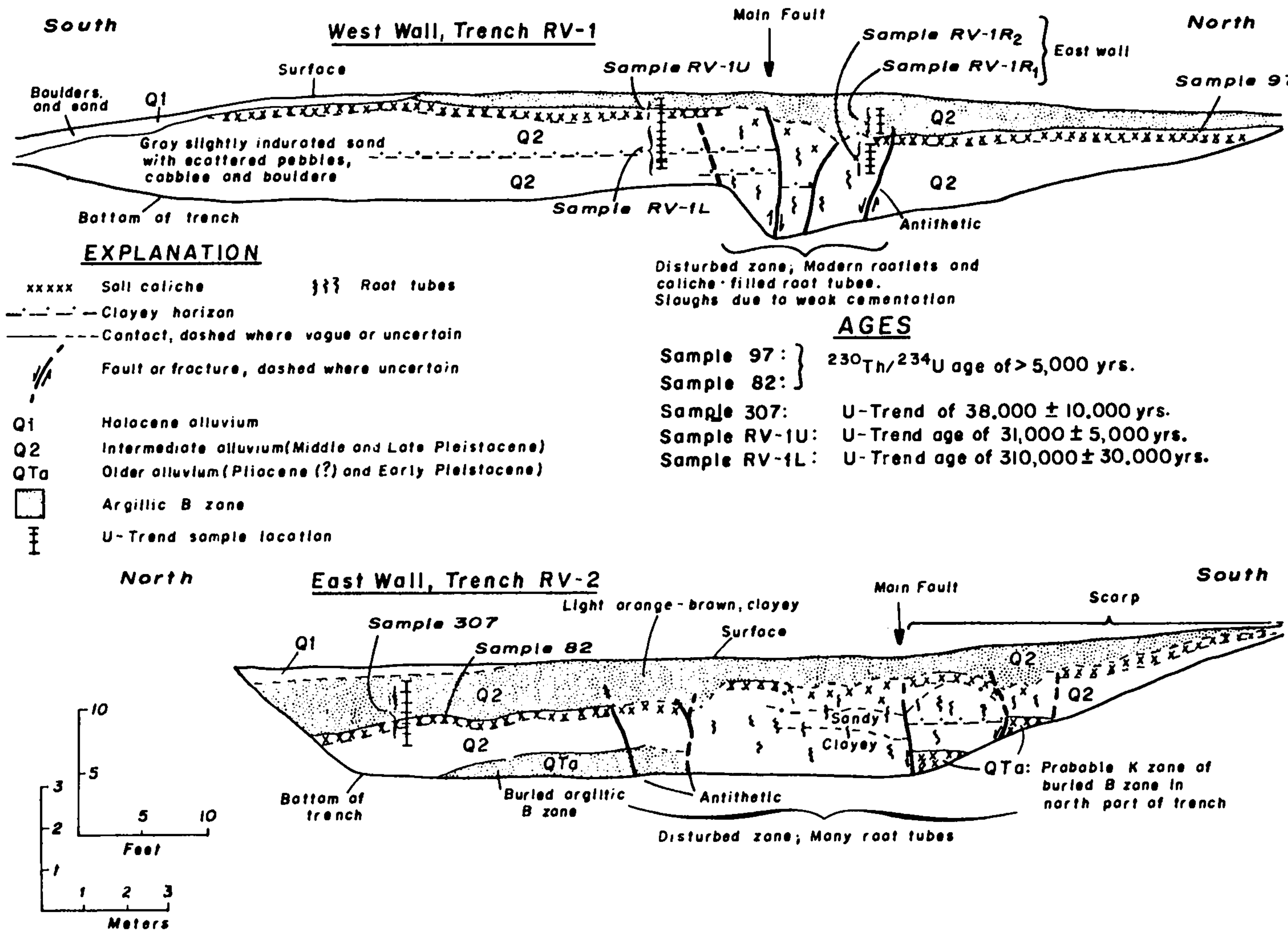

Fig. 8.
Sketch map of Quaternary faults in Rock Valley (Stop 6).

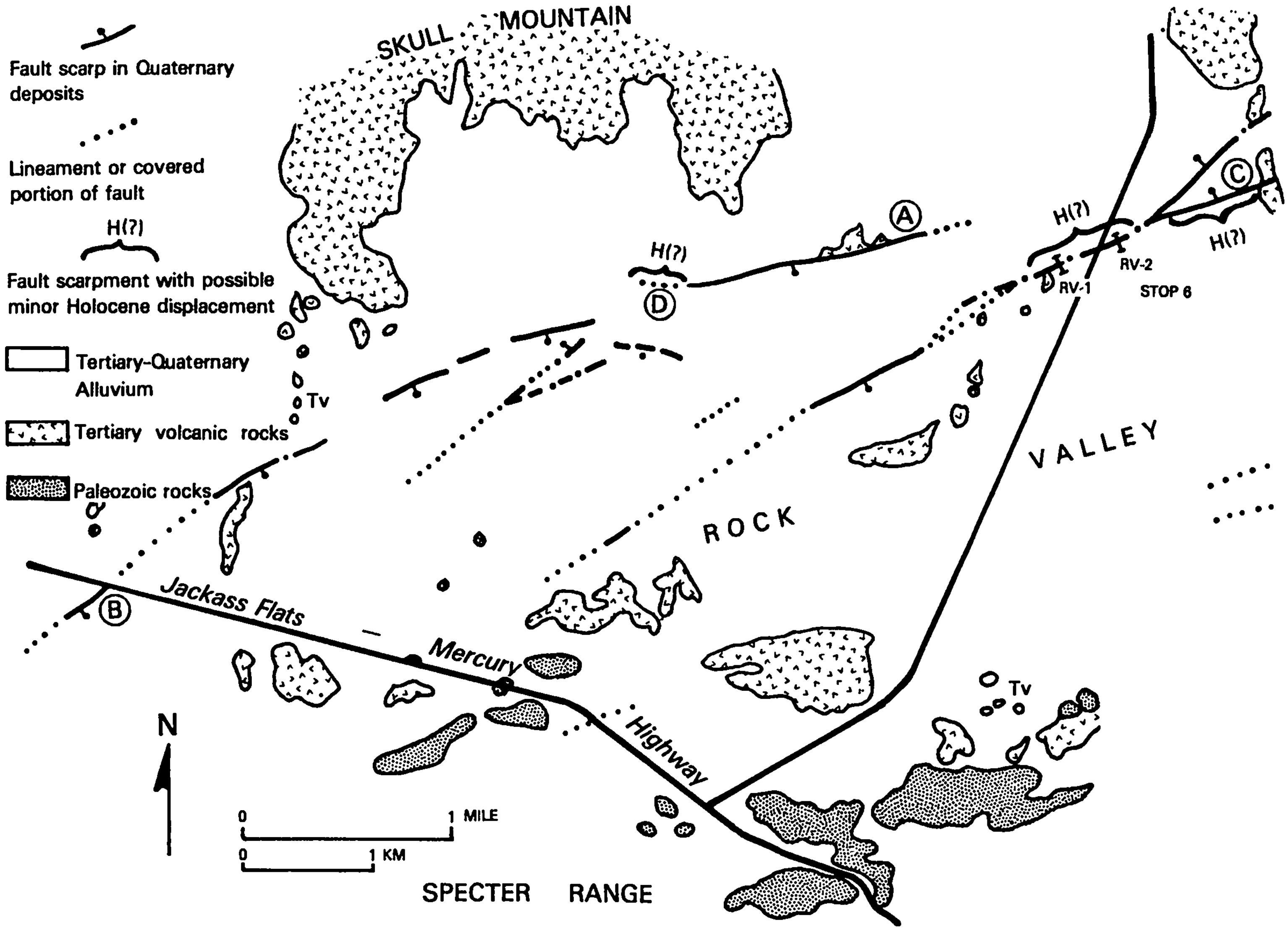

Fig. 9.
Profiles of trenches on Rock Valley fault zone (Stop 6).

U-trend dates suggest two ages of Q2 are present (Fig. 9) in the trench. At several places in the bottom of the trench are small exposures of probable QTa alluvium. On the downthrown (north) side of the fault, QTa has an argillic B-zone preserved, but on the upthrown side, the B-zone is missing, presumably as a result of erosion, and parts of a K-zone are exposed between faults on the upthrown side. A thin laminar carbonate zone, a probable K-horizon, occurs within the Q2 alluvium; it is overlain by a light orange-brown, slightly clayey B-zone. At the north end of the trench is a thin deposit of Q1 (Holocene) alluvium. QTa with a thin veneer of Q2 forms the upthrown surface south of the trench.

Ages obtained here and in trench RV-1 by uranium-series methods are by B. J. Szabo and J. N. Rosholt of the USGS, and are listed on Fig. 9. U-trend determinations from the lower part of Q2 are about 300,000 yr; dates from the upper part of Q2 are about 35,000 yr. Two samples of the laminar carbonate K-horizon gave ages of greater than 5000 yr. To the west, on a parallel fault at location A (Fig. 8), undisturbed calcrete filling a fracture adjacent to the fault gave a uranium-series age of greater than 20,000 yr, suggesting no reopening of the fracture and probably no major movement on the adjacent fault after 20,000 yr ago.

At least two faulting events appear to be recorded on the fault zone exposed in trench RV-2. The older event, which produced a small graben in QTa (Fig. 8) and was probably responsible for the preserved 1.5 + m high scarp, must have occurred after deposition of QTa and subsequent soil formation, which probably places it after 1 m.y. ago; the minimum age of the event is constrained only by the less disturbed youngest Q2 alluvium and its soil, or before (at least) 35,000 yr ago. Fault strands that offset the QTa extend upward into Q2, and vague stratification in the older Q2 suggests that it was not deposited across the scarps in QTa but faulted along with it. Therefore, it is suggested that the older event occurred after about 300,000 yr ago.

The younger event, shown by 0.3- to 0.6-m offsets of the Q2 soil and its laminar K-horizon, can only be dated as younger than about 35,000 years, the approximate minimum age of the younger Q2 (Hoover and others, 1981).

There seems to be no surface evidence of the younger 0.3- to 0.6-m offset along the old scarp and no Holocene alluvium is obviously affected, so it is reasonable to conclude that the event was probably pre-Holocene.

At location C (Fig. 8), a branch of the trenched fault extends east-northeast across QTa; it has about 0.5 m of displacement, but the scarp is very subdued. At the east end of this fault it passes into Miocene volcanic rocks where it is only possible to limit its amount of total displacement to less than 3 m.

At location D (Fig. 8), a definite lineament visible on aerial photos occurs in Holocene (Q1) alluvium; the lineament is a westward extension of a fault in alluvium that parallels the trenched fault. However, as mentioned at location A, calcrete in a fracture suggests no major movement on this fault after about 20,000 yr ago. The lineament at location D (Fig. 8) cannot be seen on the ground, and it could be only a subtle brush line where bushes have grown preferentially by sinking their roots into the fault zone through a thin cover of Holocene alluvium. Because the evidence that the latest event was pre-Holocene is not compelling, however, it is not possible to rule out an important earthquake of Holocene age on the Rock Valley fault system.

176.9 Turn left onto Jackass Flats Highway.

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

188.0 STOP 7: Arrive Mercury, visit USGS Core Library. (Depending on time schedule, the presentations planned for this stop may be given in the evening after dinner at the Mercury Steakhouse.)

Introduction

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-bit cuttings, drill core, 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, and waste-management drill holes. 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 conjoined buildings at Stop 7 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 ranging in diameter from about 2-1/2 to as much as 20 cm. Samples represent rocks penetrated in vertical, horizontal, or oblique-angle drill holes, which average about 550 m in length, but range from about 60 m to 4,171.5 m in depth and from about 2 m to 1,124.7 m in horizontal penetration. Detailed records, comprising thousands of data cards, are maintained on all samples, including date received at the library, source, and final storage or disposition.

Use of Rock Samples

Continuous core, sidewall samples, and rock cuttings stored at the Core Library have been used to resolve geologic problems encountered by programs such as nuclear test containment and radioactive waste storage. Primary minerals and whole rocks are analyzed to help correlate volcanic units found at NTS, and secondary (diagenetic) minerals have been studied intensively for their capability in inhibiting migration of radioactive nuclides.

Examples of both types of work are described below. Petrographic exhibits of various types of rock samples will be available for inspection at the Core Library.

Primary Minerals

One major project undertaken by Los Alamos National Laboratory has been to analyze phenocryst minerals and whole rocks to model the entire upper Tertiary volcanic sequence at NTS. Recent work has allowed accurate correlation of individual petrologic units, generally corresponding to member rank, and entire petrologic suites (i.e., Timber Mountain or Paintbrush Tuffs), which occur in two widely separated locations — Yucca Mountain and Pahute Mesa (Warren, 1983a, 1983b). Spatial distribution patterns of correlative petrologic units define the Timber Mountain-Oasis Valley magmatic system as the primary source for the entire volcanic package. This fact, along with supporting geochemical data, indicates that the NTS volcanic pile is indeed the effusive product of a single, large, evolving rhyolitic magma body (e.g., Hildreth, 1981) that was located beneath the present expression of the Timber Mountain caldera. The model inferred for the sequence involves two processes: injections of new magma and heat from below and continuing magmatic differentiation. Successive petrologic suites exhibit dramatically different mafic mineral chemistry, which is theorized to be the result of influxes of magma (usually basaltic) from depth. Individual petrologic units within the petrologic suites each show a distinctive feldspar chemistry (Broxton and others, 1983), which probably is caused by differences in pressure, temperature, and compositional regimes within the evolving magma body.

Good evidence for the probable cause of chemical changes between successive petrologic units can be seen in the transitional-bedded tuff unit (Tmpt), which lies between the Timber Mountain and Paintbrush Tuffs and shows petrochemistry characteristic of both volcanic suites. It contains quartz phenocrysts along with a substantial amount of forsteritic olivine (Fo_{76-80}). Several observations indicate that this nonequilibrium mixture is caused by the mixing of rhyolitic and basaltic liquids. At one drill site, an olivine-bearing alkali basalt layer was cored between the Tmpt unit and the top of the Paintbrush Tuff. Also, basalt fragments are present in all samples of Tmpt. A particularly large basalt fragment seen in thin section shows a highly reacted and poorly defined boundary with the tuff matrix, which suggests that the basalt was still liquid when mixed with the tuff. Finally, olivine xenocrysts observed in the inclusions or in Tmpt have altered rims presumably due to reaction with a rhyolitic magma having a high silica activity. These features are all illustrated in core, thin sections, chemical diagrams, and photomicrographs displayed at this stop.

Secondary Minerals - Zeolitization at Yucca Mountain

Many of the glassy volcaniclastic rocks at NTS have been zeolitized during low-temperature diagenesis. Typical hydrous mineral products of glass alteration are clinoptilolite, mordenite, and, at greater depths, analcime. Diagenetic processes and products at NTS have been described by Hoover (1968) and Moncure and others (1981).

Drill cores, sidewall cores, and outcrop samples from Yucca Mountain, Busted Butte, and vicinity contain examples of zeolitized tuff that may not have resulted from diagenesis. The lower vitrophyre (densely welded glassy tuff) in the Topopah Spring Member of the Paintbrush Tuff has been altered to smectite and the zeolite heulandite along the boundary between the vitrophyre and overlying devitrified densely welded tuff. This boundary, as seen in outcrop at Busted Butte and in drill holes, Fig. 10, is actually a transition zone about 6 m thick with interpenetrating lobes of vitric and devitrified tuff. Fractures extending downward into the vitrophyre are bordered by devitrified zones, composed mostly of feldspar and cristobalite (Vaniman and others, in preparation) as much as 0.3 m thick. The outermost portions of these fracture-controlled devitrified zones contain heulandite and smectite. Core from drill hole USW GU-3 (sample at 364.2-m depth) contains an excellent example of such alteration. The textural association of heulandite and smectite with devitrification products suggests that the hydrous minerals may have crystallized during subaerial cooling of the tuff (Levy, 1983).

The degree and extent of alteration within the vitrophyre are highly variable (Fig. 10). At some sites, the hydrous minerals form only a thin rind along the boundary between devitrified tuff and vitrophyre and comprise about 1 wt% or less of the altered vitrophyre (e.g., drill core USW GU-3, outcrop at Busted Butte). Elsewhere the vitrophyre is highly altered to depths of up to 15 m below the devitrified-vitric boundary and locally contains up to about 15 wt% heulandite and 60 wt% smectite, based on x-ray diffraction (e.g., sidewall core USW H-5 and drill core UE25a#1). The reasons for this variability are unclear. Highly altered vitrophyre has been observed only in drill cores (it may weather too easily to be preserved in outcrop), which provide minimal information about possible alteration-controlling factors such as fracture abundance. The proposed exploratory shaft at the USW G-4 site may answer some of these questions.

DAY 2

0.0 Leave Mercury heading north on Mercury Highway (Fig. 1) 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

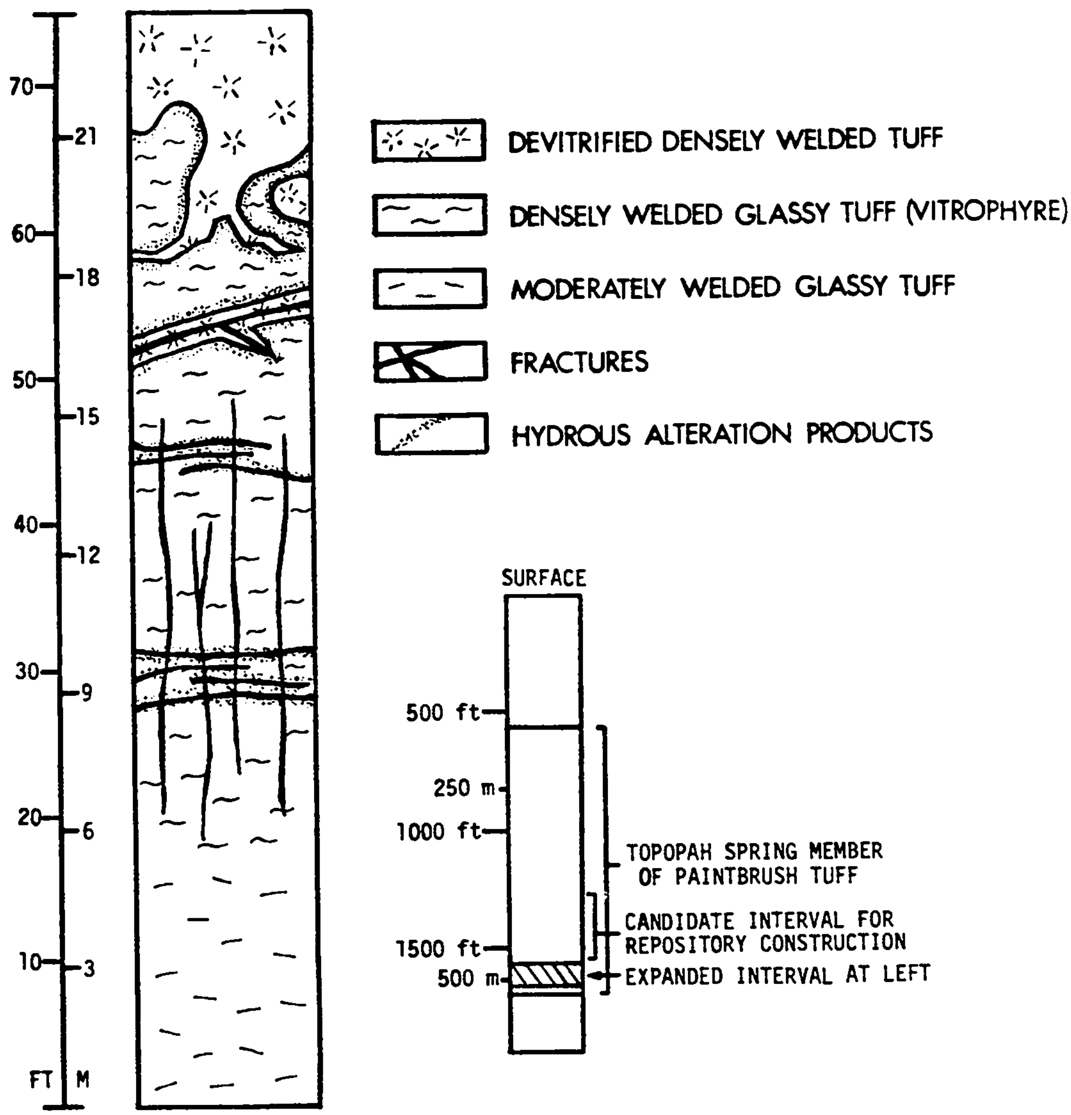

Fig. 10.
Lithology of the vitrophyre of the Topopah Spring Member of the Paintbrush Tuff (Stop 7), generalized from drill holes on Yucca Mountain.

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), a structural situation similar to that mentioned at Stop 1 in the southwestern part of the Spotted Range. The Spotted Range thrust 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 N45°-60°E trending Tertiary left-lateral strike-slip faults of the Spotted Range-Mine Mountain structural zone.

1.9 Checkpoint Pass

3.3 STOP 8: Turn left off road at Pump Station No. 4. Facing north and looking counterclockwise: Ranger 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. At 1:00 is Frenchman Lake playa and beyond is Nye Canyon, containing several basalt centers dated between 6.0 and 7.0 m.y. (R. F. Marvin, USGS written commun., 1980). 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. Stratigraphic relationships in the areas of Yucca and French Flats are shown in Fig. 11.

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 Mississipian 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. Hampel 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 contains a tuff bed dated at 29.3 m.y. (Marvin and others, 1970), which is probably airfall of the Needles Range Formation of eastern Nevada (Barnes and others, 1982). Continue north on Mercury Highway.

5.3 At junction of Mercury Highway and 5A Road proceed straight on 5A Road into Frenchman Flat.

6.0 To left, 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.

7.0 Gravel pits to right provide material used in the stemming 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.

10.0 Y in road. At 9:00 observe structures tested by nuclear blasts.

11.6 At 10:00 dark re-entrant is vitrophyre lava of the Wahmonie Formation onlapped by Topopah Spring Member of the Paintbrush Tuff.

12.5 Turn left.

12.9 <u>STOP 9</u>: Turn left onto gravel road. Radionuclide Migration (RNM) project site (Fig. 12). The RNM project was initiated in 1974 to

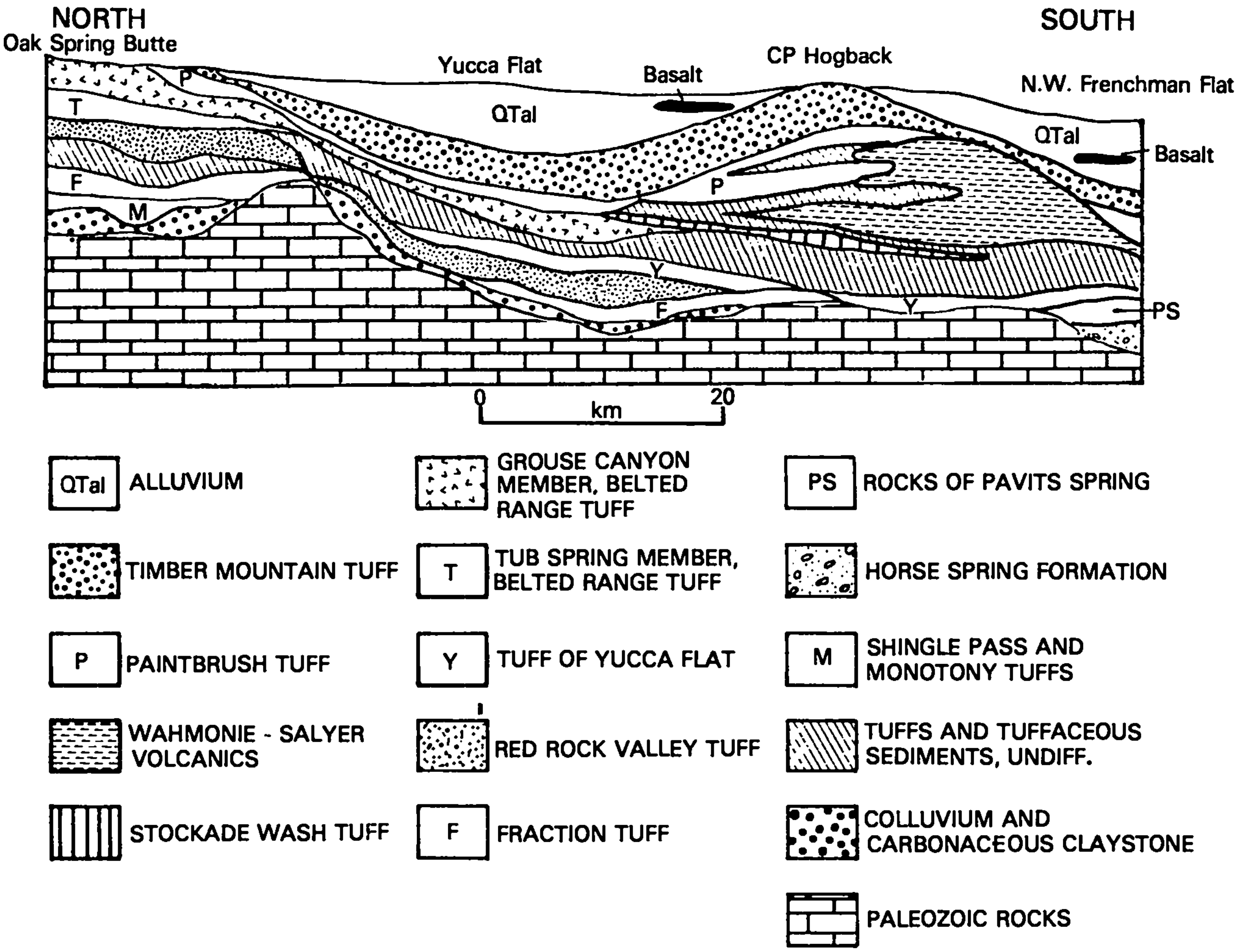

Fig. 11.
Diagrammatic cross section from Oak Spring Butte to northwestern Frenchman Flat, NTS, Stops 8 and 10.

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, it was judged that the alluvium constituted a good medium for hydrologic studies because it was more permeable than tuff and did not have large fissures or cracks through which the water might selectively flow.

The Cambric field studies can be divided into two phases. (1) The Cambric cavity region was re-entered in 1974, and samples were taken to determine the radionuclide distribution between the solid material and water. (2) 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-25 satellite well has been pumped at the rate of about 600 gal/min. Samples are analyzed weekly for tritium. Beginning in the summer of 1978, tritium was first detected and reached a peak of 7000 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 left.

15.4 Turn right at junction with Mercury Highway. Wahmonie rhyodacitic lavas form hills to west.

17.0 Intersection of Mercury Highway and Cane Spring Road.

18.0 Dark layer low on cliff at 3:00 is the upper part of the Wahmonie lavas underlying vitrophyre of the Topopah Spring Member.

18.5 In distance at 10:30 is blue-gray limestone of the Cambrian Bonanza King Formation Limestone thrust over brown argillites of the Devonian and Mississippian Eleana Formation, overlapped by Tertiary volcanic rocks.

20.5 CP Hogback at 1:30 is composed of faulted blocks of Ammonia Tanks Member of Timber Mountain Tuff dipping toward you.

22.3 Cambrian Carrara Formation at 11:00 is folded into asymmetric anticline (McKeown and others, 1976). Vitrophyre of the Topopah Spring Member at 10:00; the same unit forms the low hill at 1:00, where it is faulted against the Ammonia Tanks.

23.7 Crest of CP pass.

24.7 STOP 10: View of Yucca Flat from News Knob. Turn right onto road north of warehouse by News Knob. Facility to west is Control Point (CP), which houses equipment used to monitor nuclear tests. Climb News Knob. Facing northward, at 3:00 to 1:00 is Halfpint Range; at

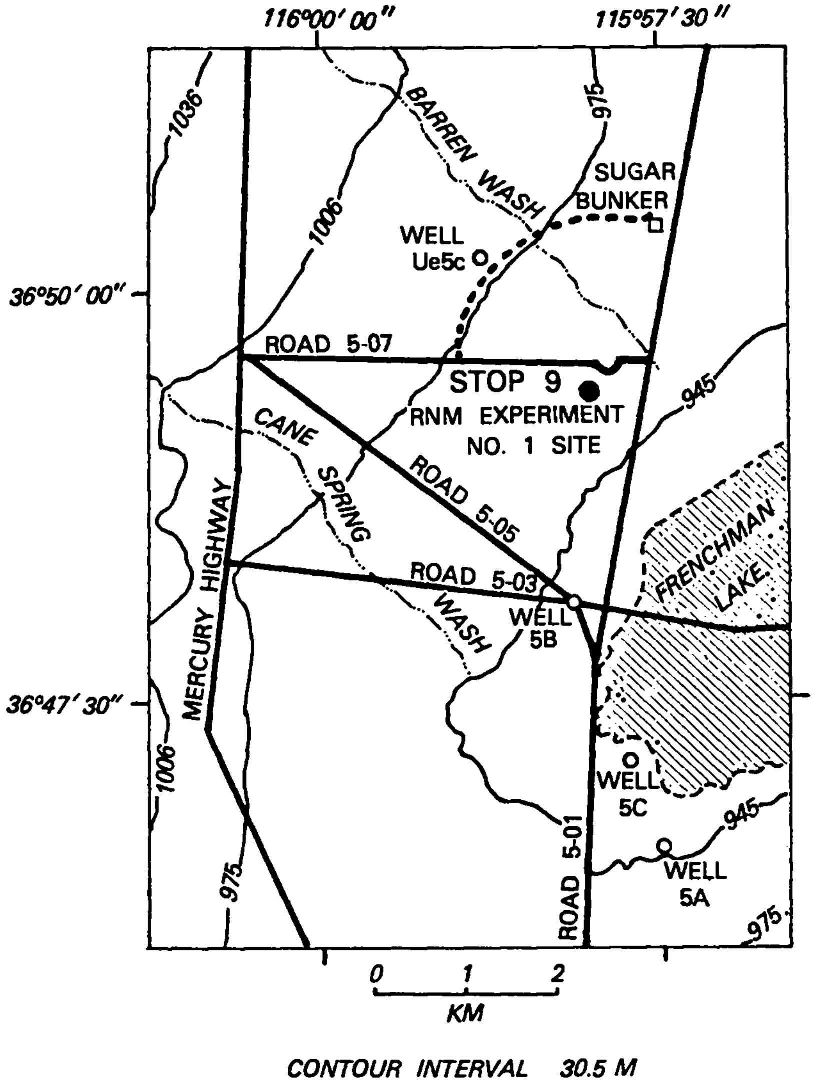

Fig. 12.
West-central Frenchman Flat, showing location of the RNM Experiment No. 1 site (Stop 9).

1:30 Slanted Buttes are capped by Rainier Mesa Member; at 1:00 is Banded Mountain (type locality of the Banded Mountain Member of the Bonanza King Formation). At 12:00 is Oak Spring Butte cut on the east side by the Butte Fault (a northward extension of the Yucca Fault) which drops the caprock of Grouse Canyon Member 425 km down to the east; to the left of Oak Spring Butte is Argillite Ridge and Twin Peaks, which is on the east flank of a broad depositional syncline in Tertiary tuffs and underlying sediments with thin laminae of coal. At 10:00 - 11:00 is Rainier Mesa, at 9:30 is Tippipah Point, to the west at 7:00 to 10:00 are Paleozoic rocks of the CP Hills.

The southwest edge of Yucca Lake playa is parallel to and coincident with an element of the Walker Lane belt -- the Yucca-Frenchman right-lateral shear and flexure zone (Fig. 13). This structure trends northwest for about 40 km from the Spotted

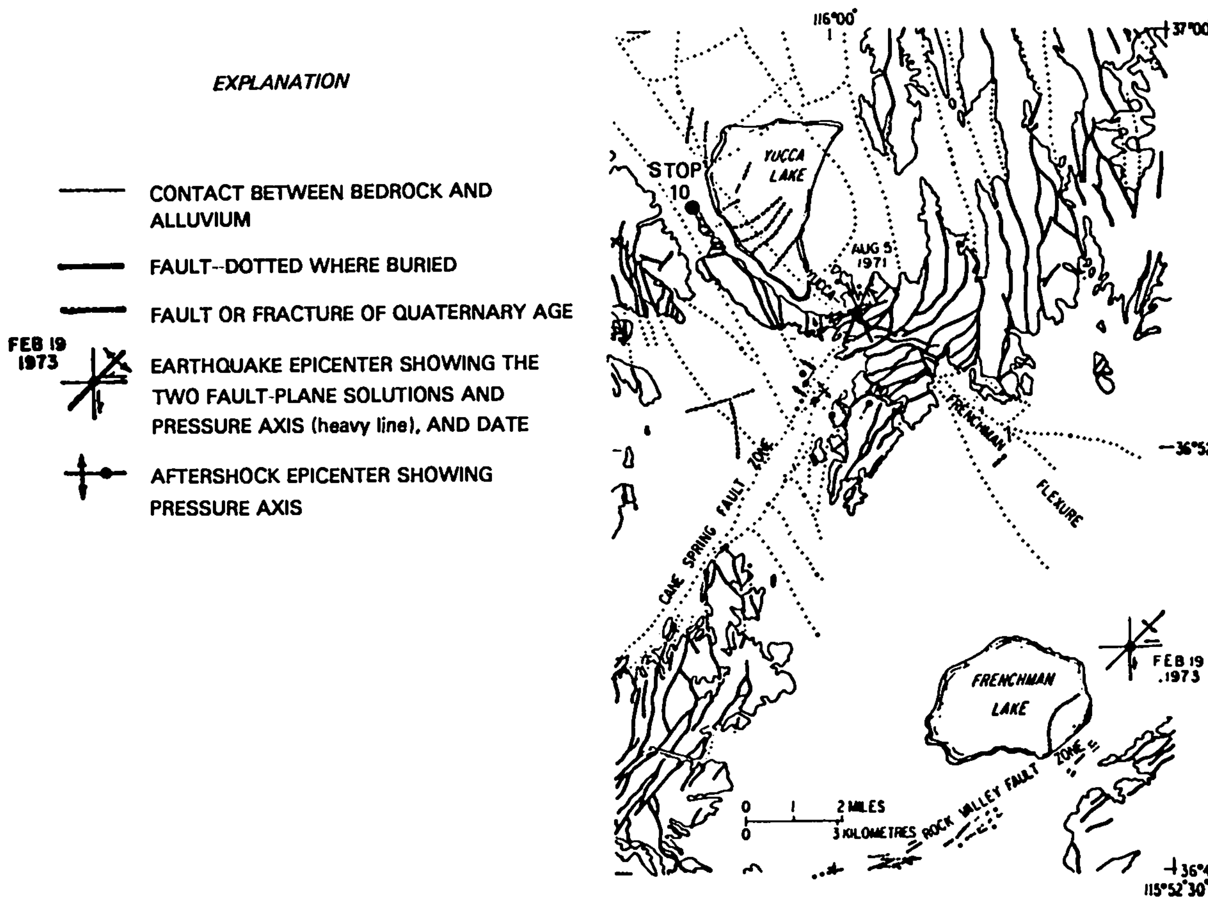

Fig. 13.
Southern Yucca Flat and Frenchman area, showing structural pattern, Quaternary faults and fractures, and location of earthquakes, their aftershocks, fault-plane solutions, and pressure axes (Stop 10).

Range, across northern Frenchman Flat, through the hills between Yucca and Frenchman Flats, and along the southwestern side of Yucca Flat. It is exposed only in the hills southeast of Yucca Flat, where it consists of a complex shear zone exhibiting right-lateral drag. This zone also marks the termination of a major system of northeast-striking, essentially left-lateral faults. Major fault zones of this Spotted Range-Mine Mountain structural zone include the Mine Mountain, Cane Spring, and Rock Valley faults.

Extensive drill-hole data collected in Yucca Flat have been used to construct isopach and structure contour maps of Cenozoic units occupying the basin. The configuration of these units indicates that the north-trending faults controlling present-day basin morphology were inactive during deposition of volcanics from approximately 25 to 11 m.y. However, after 11 m.y., the overlying sedimentary sequence was strongly influenced by these faults. In particular, an inordinately thick section of upper Tertiary and Quaternary alluvium occurs at the southwestern end of Yucca Flat (Fig. 14). It is probably a pull-apart developed at the intersection of the north- and the northeast-trending faults (Ander,

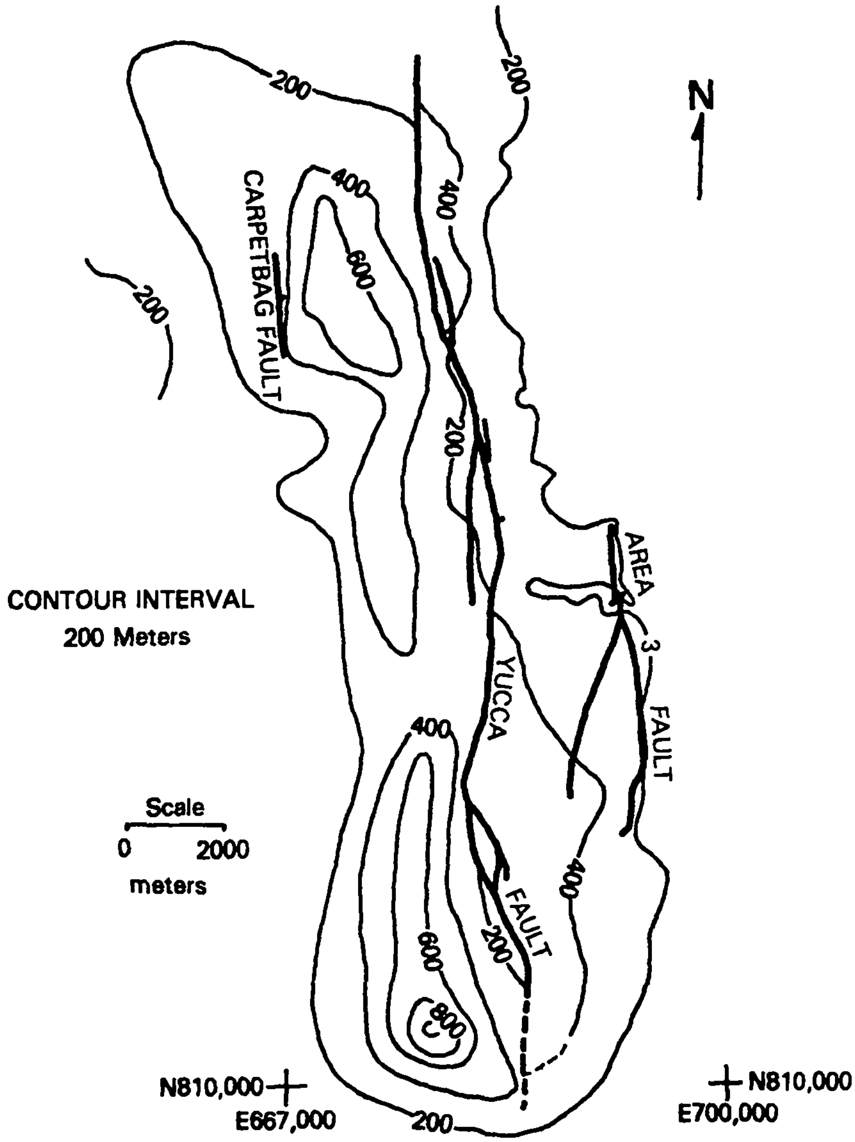

Fig. 14.
Isopach map of upper Tertiary and Quaternary alluvium in Yucca Flat (Stop 10).

1983; Ander and Oldow, 1983; Ander, 1984), or between the north-trending Carpetbag fault and Yucca-Frenchman shear and flexure zone (W. J. Carr, 1984). Geologic relations, as well as slickenside analyses, indicate that the pull-apart, along with much of Yucca Flat, was formed during a N78°W directed extension. Sometime after deposition of much of the alluvium, probably about 8 m.y. ago, the extension direction rotated to the currently active direction of N60°W (Ander, 1983; Ander and Oldow, 1983; Ander, 1984). Schematic east-west cross sections of north, central, and south Yucca Flat are shown on Fig. 15.

In the last 5 yr, during operation of the southern Great Basin seismic net, the Yucca-Frenchman shear and flexure zone has been a boundary between the seismically active Spotted Range-Mine Mountain structural zone to the southwest and a much lower rate of activity

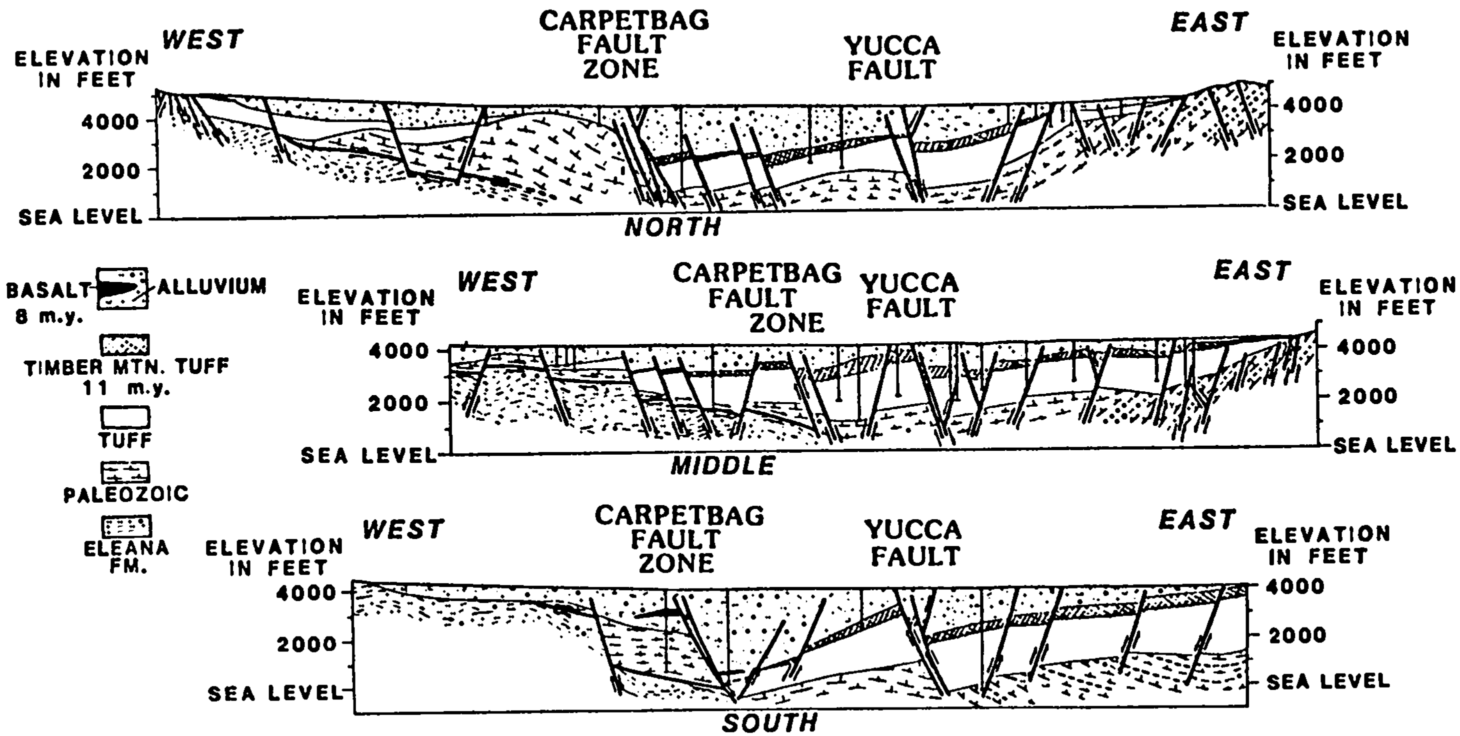

Fig. 15.
Geologic sections across Yucca Flat (Stop 10).

to the northeast. Before the present seismic network, two medium-sized earthquakes (ML 3.5-4.0) occurred near the Yucca-Frenchman shear and flexure zone, one in 1971 at the intersection of the Cane Spring fault zone, the other in 1973 near the intersection of the Rock Valley fault zone. In the case of the event near Yucca playa (the Massachusetts Mountain earthquake), slip occurred as either right-lateral motion on a northwest-striking fault plane or left-lateral motion on a northeast-striking fault plane.

Yucca and Frenchman playas display a feature found in most playas in tectonically active areas: tension cracking. Air photos show that Frenchman Lake playa cracked at some time just before 1950, as did Yucca playa, but cracking, now nearly obliterated, recurred on Yucca playa in 1960, 1966, and 1969 (Fig. 16), migrating in a southeastward direction. The evidence that the cracking is tectonic and not due to desiccation is as follows: (1) the cracks in Yucca playa and in all the other playas of the region trend consistently north to northeast, regardless of playa shape; (2) the cracks tend to be curvilinear, not polygonal; (3) in Yucca playa the cracks trend at right angles to the gravity gradient and to the side of the basin, contrary to what would be expected if they were caused by shrinkage resulting from desiccation; (4) one of the cracks is aligned with a small fault scarp (now obliterated) in alluvium, which in turn trends toward a bedrock fault just south of News Knob; (5) topographic and leveling data for Yucca playa indicate no subsidence has occurred in the area of the cracks, as might be expected with loss of soil moisture; (6) large quantities of water flow into the cracks when they are new, indicating they go to considerable depths, probably into rocks beneath the alluvium; (7) although no vertical offset occurred across the cracks, detailed topography suggests slight displacements in alluvium beyond the northeast end of the cracks.

Return to Mercury Highway and turn right.

25.2 Orange Road junction on left, weather station on right.

27.0 Tweezer Road on right. Mine Mountain at 9:00 has Devonian carbonate rocks thrust over the Devonian and Mississippian Eleana Formation (Orkild, 1968; Stop 16).

28.0 Area 6 Birdwell casing yard.

31.5 Brick houses at 9:00 are structures built during era of aboveground nuclear testing.

31.8 Reynolds Electric Company drilling support yard.

33.1 At Y (BJ Wye Junction) in road veer left onto Rainier Mesa Road.

40.2 East-facing Yucca fault scarp at 3:00.

41.2 Turn left onto Road 2-04 (marked U2FA).

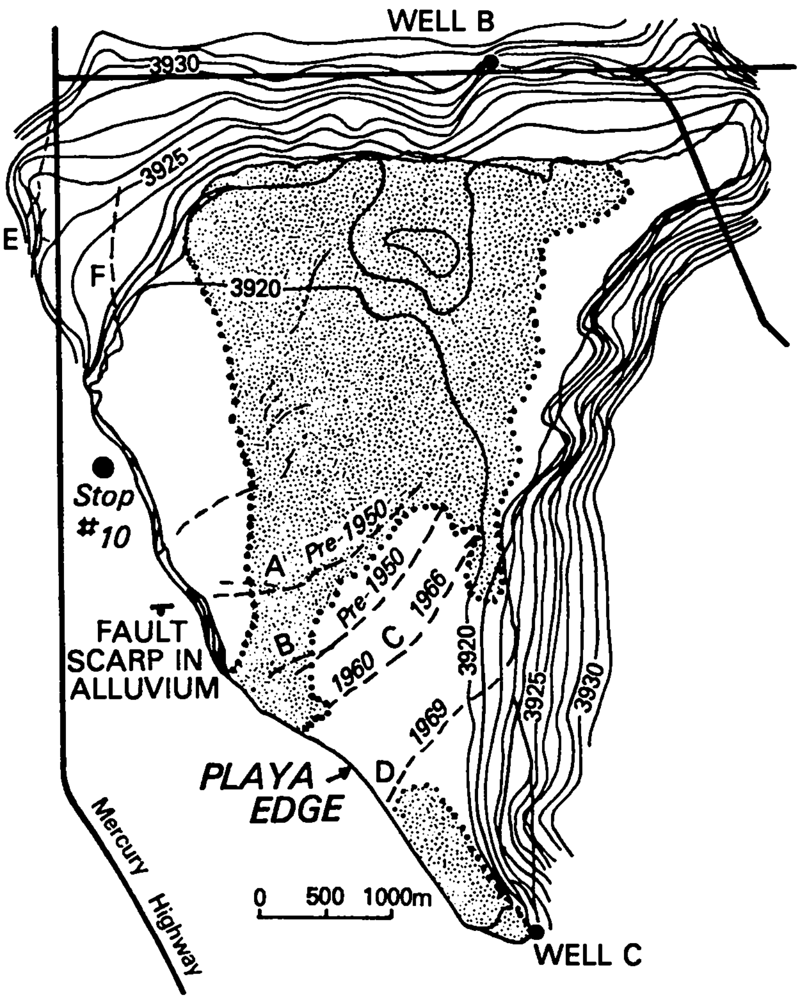

Fig. 16.
Map of Yucca Lake playa area showing cracks (lettered A to F) and detailed topography. Shaded area is apparently depressed with respect to unshaded areas, based on distribution of water in the lake in March 1973 (Stop 10).

42.0 STOP 11. Morphology of the Carpetbag fault. Park bus and walk 0.3 miles to Carpetbag fault scarps (Fig. 17).

The north-trending Carpetbag fault system consists of a series of east-dipping Basin and Range style faults that traverse the length of Yucca Flat on the western side (D. L. Healey, USGS unpublished gravity data). Post-tuff dip-slip displacement is 300 m in the area of Carpetbag scarp (Ander, 1984); a large amount of right-lateral motion has also been postulated (Carr, 1974). Two major fault scarps of the system were propagated to the surface as a result of the detonation of the Carpetbag event in 1970. This event also caused the Carpetbag sink and a series of concentric cracks extending out about 1000 m from the edge of the sink. This type of surface cracking may have been due to detonation of the nuclear device below the static water level, a practice now avoided.

The graben bounded by the two fault scarps extends for about 2600 m on the western side, where 11 to 590 cm of post-testing dip-slip

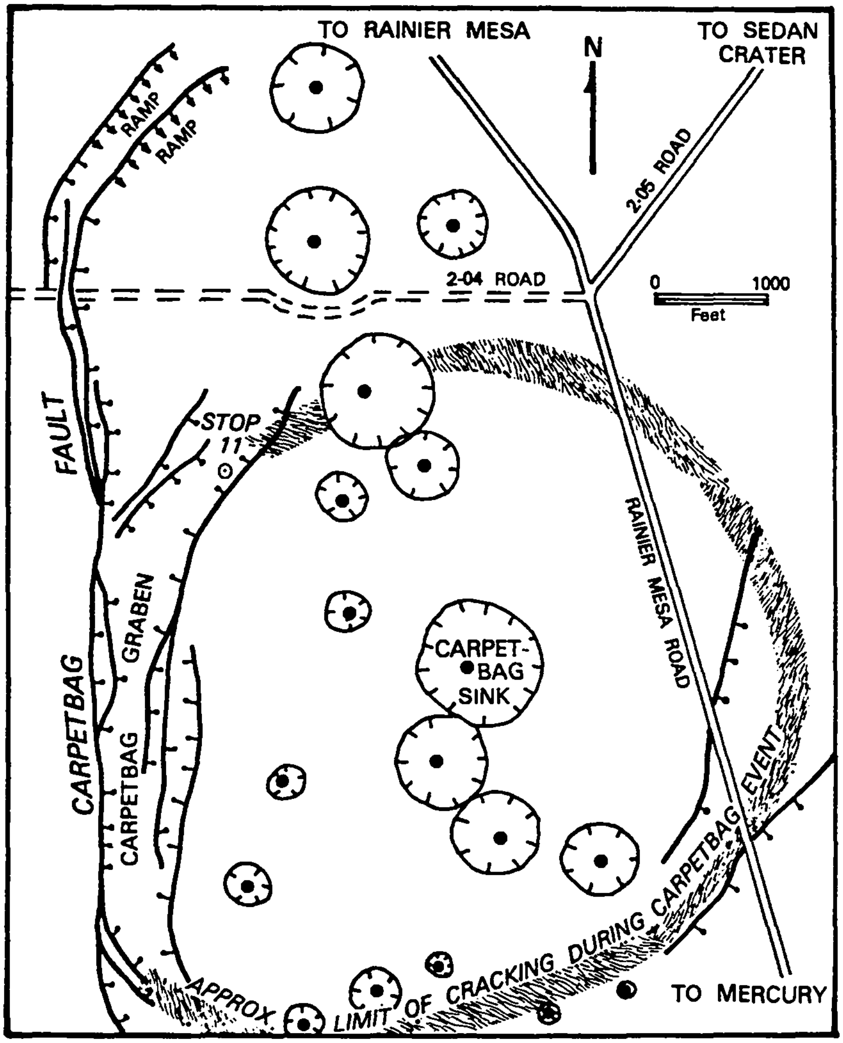

Fig. 17.
Carpetbag fault system (Stop 11).

displacement has been documented on the western fault scarp. On the eastern side, three fault strands ranging in trend from N-S to N40°E (E. C. Jenkins, USGS written commun., 1973) form two major scarps, 1525 m long, with dip-slip displacements of 9 to 490 cm. About 0.9 m of right-lateral motion has been recorded along the system since 1970.

Ramp features extending northeast from the northern end of the western fault scarps have surfaces that dip 10° to the southeast and are bounded by low scarps at the toe of the slope. Trenching Fig. 17 reveals that the ramps are shallow features that die out a short distance from the main fault. The ramps are proposed as resulting from one or more of the following possible causes: (1) surface expression of splays or "horsetails" from the main Carpetbag fault; (2) lowering of ground-water table causing surface subsidence; and (3) underground nuclear testing causing differential ground subsidence.

Surficial deposits exposed in the wall of the graben help constrain the ages of recent fault movement. Young fluvial sands, gravel, and slopewash postdate the last major movement on the Carpetbag fault. These deposits have stage I soil-carbonate morphology of Gile and others (1966) and are probable equivalents of Holocene units described by Hoover and others (1981). The older units predating fault movement have a thin K-horizon with stages III to IV morphology and have uranium-trend dates of 270,000 to 310,000 yrs (J. N. Rosholt, USGS written commun., 1983). Uranium-series dating of secondary carbonate along fractures brackets the displacement between 93,000 and 37,000 yr (Knauss, 1981), which correlates well with the lack of distinguishable fault scarps in the younger (Holocene?) gravels before nuclear testing in 1970.

42.8 Turn left on Rainier Mesa Road then turn right on 2-05 Road (Fig. 17).

44.4 Yucca fault scarp (early Holocene) in foreground at approximately 12:00 is 18 to 24 m high. Climax stock in background.

45.8 Yucca fault scarp crosses road. Roughness of road is due to repeated fault displacement triggered by nearby nuclear tests.

46.5 Turn right to Sedan Crater.

46.9 STOP 12: Sedan Crater and discussion of containment geology at NTS. Underground tests require a comprehensive geologic site characterization to help ensure complete containment of radioactive debris and gases created by the nuclear explosion. Based on device parameters, an appropriate site is selected. Following completion of the emplacement hole, using large-hole (up to 3.7 m in diameter) drilling techniques developed at the NTS, it is sampled and logged with large-diameter tools that are also unique to the test site. These data are evaluated and the detailed site characterization is prepared (Fig. 18). Items of interest are the mineralogy/petrology, stratigraphy and structure, surface features both natural and cultural, densities, moisture contents, noncondensible gas generation (CO_2), depth to the static water level, acoustic impedances, and any unusual features. Adequate characterization often requires drilling exploratory holes, detailed geophysical surveys, and other specialized investigative techniques such as borehole photography. Most of the tests are conducted in alluvium or tuff, but some have been in carbonate or granitic rocks. Once the geologic setting is understood, the response of the medium to the explosion is predicted and the potential for complete containment of the radioactivity is evaluated. Not until the site has been thoroughly reviewed and approved by the DOE's panel of experts is the experiment allowed to proceed.

The explosive device is placed into a large rack that contains the diagnostic systems. This rack is lowered into the hole, along with more than one hundred power and signal cables, using a wire rope harness on a large crane. After detonation, the effects on the geologic medium are evaluated through surface mapping, ground motion measurements, seismic information, and other data as available.

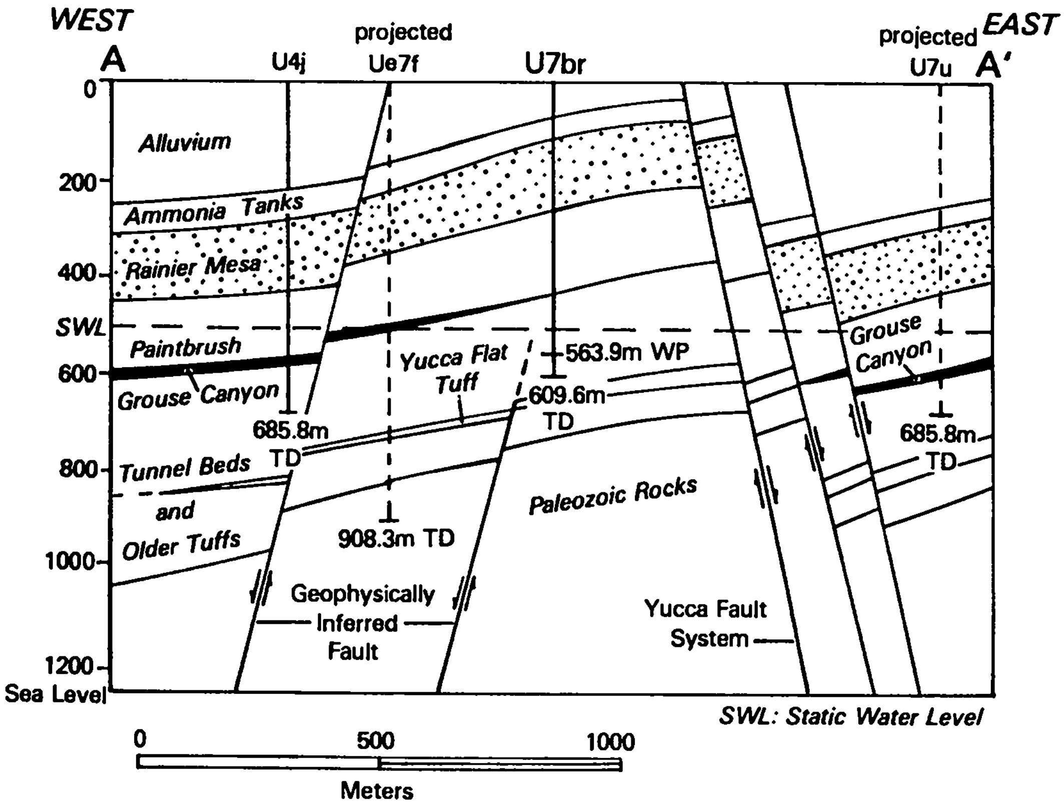

Fig. 18.
Geologic section through an emplacement site (Stop 12).

Peaceful nuclear explosions in the U.S., as encompassed in the Plowshare Program, began as a series of meetings and panels in 1956. Massive nonnuclear high-explosive excavation and fracturing experiments were conducted at the NTS to derive proper scaling laws to be applied to the use of low- to intermediate-yield nuclear explosives for excavations. In all, some 15 nuclear cratering experiments were conducted between 1962 and 1968, with a few experimental underground applications, mostly gas stimulation, taking place in New Mexico and Colorado (Projects GNOME, GASBUGGY, RULISON, RIO BLANCO) as late as May 1973. The USSR has used nuclear explosives for oil and gas stimulation as well as for construction of earthen dams.

Sedan crater, created in one second on July 6, 1962, testifies to the excavation ability of nuclear explosives. A 100-kT device was detonated at 193.5-m depth in tuffaceous alluvium. The resultant crater is 390 m in diameter, 97.5 m deep, and has a volume of approximately 5 x 10^6 m^3. The height of the lip ranges from 6 to 30 m above preshot levels. Ejecta were found as far as 1770 m from ground zero. The seismic energy release was 2.45 x 10^{18} ergs, equivalent to an earthquake magnitude of 4.8. A cross section through the crater lip (Fig. 19) shows thrusted and overturned marker beds resulting from the explosion in this poorly indurated alluvium.

47.3 Return to paved road and turn left at stop sign.

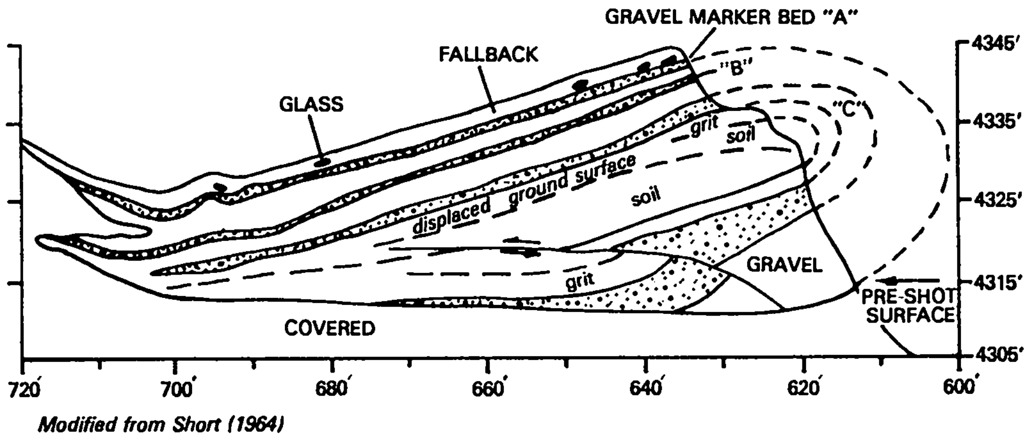

Fig. 19.
Geologic section through the Sedan Crater lip exposed in cross section trending N58°W from ground zero (Stop 12).

48.9 Turn right on Road 2-07.

51.4 Turn right onto Rainier Mesa Road.

55.6 Area 12 camp on right. At 3:00 are the orange to brownish-gray tuffs of the Miocene Tunnel Beds. The welded unit overlying the Tunnel Beds approximately two-thirds of the way to the top is Miocene Grouse Canyon Member of the peralkaline Belted Range Tuff. Keep to left on Stockade Wash highway, continuing southward toward pass at south side of Rainier Mesa.

57.3 Thrust fault between the Devonian Devils Gate Limestone and Devonian and Mississippian Eleana on right.

57.9 To left observe Tunnel Beds filling paleovalley in Eleana Formation. Bright red zones are areas of intense weathering and alteration.

59.1 Tuff/Paleozoic contact, very altered.

60.4 STOP 13: Pass on south side, Rainier Mesa (see Fig. 1). Walk approximately 100 m to eastern overlook. To the east is erosional unconformity of Tunnel Beds on Eleana. In distance to northeast is the Groom Lake Playa. Pahranagat Range on skyline. On Survey Butte, just to left of Area 12 camp, are small faults in Rainier Mesa Member. In same area, welded Grouse Canyon Member can be seen filling erosional valleys in Tunnel Beds.

Lunch. Return to Stockade Wash Highway, turn right.

61.6 Stockade Wash Tuff forms bluffs on either side of Stockade Wash and thickens westward. Mesas on both sides of road are capped by resistant ledges of Tiva Canyon and Rainier Mesa Members, downfaulted to the west along outer ring fracture faults associated with the Timber Mountain caldera collapse.

62.1 Wide valley held up by dip slope of densely welded (erosion resistant) but unexposed Grouse Canyon Member. Configuration of less resistant on resistant units allows valley to widen but inhibits down-cutting.

64.1 Intersection with Pahute Mesa Road, continue straight ahead.

64.4 Road parallels rim of caldera marked by cuesta of onlapping intra-caldera Ammonia Tanks Member to left. Flat-lying tuffs of Area 20 underlying Stockade Wash Tuff to the right.

65.6 At 1:00 is Rattlesnake Butte capped by Rainier Mesa Member. Road goes up dip slope of welded peralkaline Grouse Canyon.

66.6 Road cut exposes peralkaline air-fall tuff above welded Grouse Canyon. At 12:00, upthrown fault block approximately 1 km from road is welded Grouse Canyon.

67.9 Contact between Grouse Canyon welded tuff and underlying Grouse Canyon air-fall tuff.

69.6 Grouse Canyon air-fall tuff thickens westward toward Split Ridge.

72.0 STOP 14: Near the rim of Pahute Mesa (see Fig. 1), bus drops participants off and continues to Echo Mesa Road to turn around (1.1 km). To south overlooking Big Burn Valley, cuestas of Ammonia Tanks 4 km away are dipping into the Timber Mountain caldera, with Stockade Wash Tuff and Grouse Canyon Member forming the walls of the caldera. On the distant skyline to the south, the rhyolite of Shoshone Mountain overlies the southeastern caldera wall and rim. Visible on the far skyline to the southeast are the Spring Mountains. Rainier Mesa can be seen to the left, capped by Rainier Mesa Member; the bench part-way up side of mesa is formed by Tiva Canyon Member. Cuestas ringing Big Burn Valley are welded Grouse Canyon Member.

In the road cut we see bedded vitric tuff of Area 20. At the western end of the road cut, this tuff is overlain unconformably by a 2-3-cm-thick ash fall and the base surge of the Rainier Mesa Member. The entire section of Paintbrush Tuff is absent here. Although the spectacular erosional unconformity might suggest erosional stripping of the Paintbrush, no part of the Paintbrush other than its uppermost member, the Tiva Canyon, has been found by geochemical sampling in this general area. The absence of Paintbrush Tuff at this exposure and the thinning of the Rainier Mesa Member toward the southern rim of Pahute Mesa indicates that the rim of Pahute Mesa was topographically high during all of Paintbrush time.

To the northwest of us is located a major volcano-tectonic subsidence feature, the Silent Canyon caldera (Orkild and others, 1968; 1969). This is actually a very complex feature, all but hidden beneath outflow sheets from the Timber Mountain caldera to the south. The earliest volcanism associated with the Silent Canyon center erupted >200 km^3 of comenditic (highly alkalic rhyolite) magma, largely beneath Pahute Mesa and the Belted Range to the east

(Noble and others, 1968). Major outflow sheets are the Tub Spring and Grouse Canyon Members of the Belted Range Tuff, the latter (younger) unit exposed in the valley below. Calcalkaline volcanic rocks containing Mg-rich mafic minerals are interbedded with the Belted Range Tuff.

Following cessation of comenditic volcanism, a sequence of calc-alkaline volcanics containing Fe-rich mafic minerals was erupted. These are the tuffs and lavas of Area 20 at Pahute Mesa, and the Crater Flat Tuff, tuffs and lavas of Calico Hills, and the rhyolitic (lower) portion of the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain. Return to bus and continue down Pahute Mesa Road.

80.0 Turn right (south) on Pahute Mesa Road.

80.7 Turn right on airstrip road entering caldera. Ammonia Tanks Member at 3:00.

81.2-82.2 Traverse alluvial caldera fill.

84.2 End of pavement.

84.3 Turn right onto Road 18.01. At 7:00 to 8:00 is Timber Mountain resurgent dome. Also to southwest are 2.8 m.y. basalt cinder cones and lavas of Buckboard Mesa. The basalts were erupted where Basin and Range faults intersect inner caldera ring fracture zone.

86.0 Cuesta of Ammonia Tanks Member, which was banked into scallop of caldera.

86.3 Unconformable contact and debris flows between Split Ridge lavas to left and Ammonia Tanks tuff to right.

87.0 At 9:00 is Split Ridge lava overlain by bedded peralkaline tuffs and welded Grouse Canyon Member.

87.4 STOP 15: Timber Mountain caldera wall at Well 8 (Fig. 20). Here we are in a deep paleotopographic "scallop" in the wall of Timber Mountain caldera (Byers and others, 1976a). At this scallop the topographic wall of the caldera changes direction from northerly to westerly. This wall is the result of cauldron subsidence related to the eruption of more than 1250 km^3 of the Rainier Mesa Member, the older of two major ash-flow tuff sheets of the Timber Mountain Tuff (Byers and others, 1976b). The caldera collapse associated with the younger ash-flow sheet, the Ammonia Tanks Member, is nested within the collapse area associated with the eruption of the Rainier Mesa (Byers and others, 1976a, 1976b). Timber Mountain resurgent dome in the central part of the caldera (Carr, 1964; Carr and Quinlivan, 1968) occurred soon after collapse related to the Ammonia Tanks Member and exposes about 1000 m of the intracaldera facies of the Ammonia Tanks (Byers and others, 1976a, 1976b).

At Well 8 (Fig. 20), the cuesta rim to the south is an eroded rim of onlapping Ammonia Tanks ash-flow tuff, underlain by interbedded coarse reworked tuff and cauldron subsidence-related debris flows.

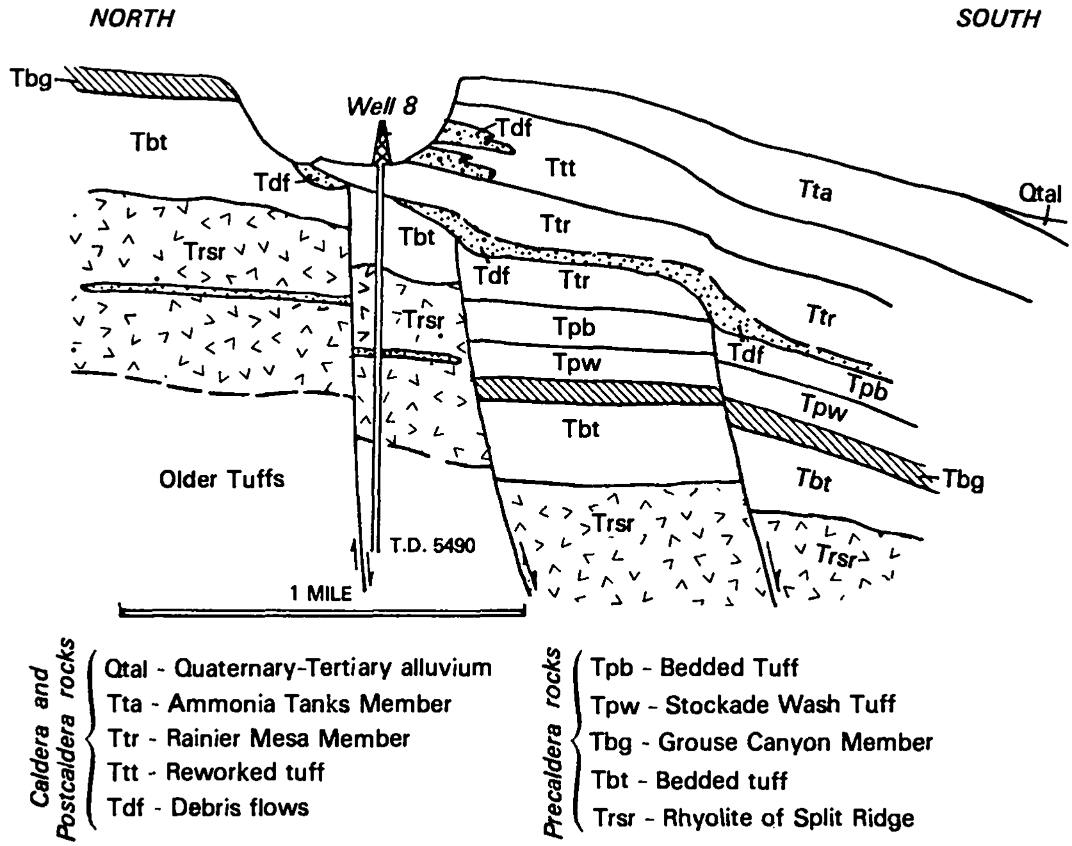

Fig. 20.
Sketch of geologic relations at Well 8 (Stop 15).

To the north, the rim of the caldera wall is welded Grouse Canyon underlain by bedded peralkaline tuff onlapped by the upper lithic-bearing, intracaldera Rainier Mesa Member of quartz latitic composition. Lithic clasts in the Rainier Mesa are derived not only from the welded Grouse Canyon rim above but also from a basal partially welded rhyolitic Rainier Mesa ash-flow, which was formerly in the caldera wall above the Grouse Canyon but is now eroded away. Sparse granitic xenoliths, presumably from depth, indicate crystalline rocks above the magma chamber at the site of Rainier Mesa ash-flow tuff vent(s). Well 8 penetrated 45 m of quartz latitic facies of the uppermost Rainier Mesa Member before penetrating precaldera rocks. The quartz latite represents the lowest erupted portion of the magma column, 11.3 m.y. ago (Marvin and others, 1970).

90.4 Turn left onto Airstrip Road.

94.1 Turn right on Pahute Mesa Road.

94.4 Road parallels wall of caldera, with intracaldera Ammonia Tanks on right lapping on wall of Stockade Wash Tuff underlain by Grouse Canyon Member.

96.5 Leave caldera wall. At 12:00 are Big Butte and Sugar Loaves capped by Tiva Canyon Member. At 9:00, Pinyon Butte.

98.3 Altered multicolored tuffs and thin Grouse Canyon Member cut by minor fault crossing the road.

98.9 Contact between Redrock Valley Tuff and underlying Eleana Formation at 1:00. Valley at 9:00 to 12:00 is type locality of Redrock Valley Tuff.

99.2 On left, contact between Redrock Valley Tuff and Eleana Formation in road cut.

101.5 Highway parallels Syncline Ridge at 12:30 formed by Pennsylvanian and Permian Tippipah Limestone.

103.8 Pass the axial trace of Syncline Ridge, best exposed on right (south) side of bus; 1100 m of Pennsylvanian and Permian Tippipah Limestone is exposed in the west limb. From 1977-79, several drill holes were drilled on the flanks of Syncline Ridge to test the underlying argillite of the Eleana for suitability as a nuclear waste repository. The site was rejected, primarily because of its proximity to nuclear testing.

105.7 Turn right on Orange Road (Tippipah Highway).

111.0 Turn right on Mine Mountain Road.

112.9 Entering east side of Mine Mountain, Devils Gate Limestone thrust over Eleana Formation.

113.2 Thrust contact between red Eleana argillite and upper plate of light gray Devils Gate Limestone.

113.5 Structure to left is old mercury retort.

114.3 STOP 16: Mine Mountain thrust. The route to this stop crosses the Mine Mountain thrust fault, which separates argillite of the Devonian and Mississippian Eleana Formation in the lower plate from carbonate rocks of the Devonian Devils Gate Limestone and Nevada Formation in the upper plate (Fig. 21). Overlook Point offers an excellent panorama of Mine Mountain thrust and of Yucca Flat.

Several thrust faults in the region of the NTS emplace upper Precambrian and lower Paleozoic rocks on top of middle and upper Paleozoic rocks. These occurrences include the Mine Mountain and CP thrusts in the Yucca Flat area, the Specter Range thrust west of Mercury, and the Spotted Range thrust (also seen from Stop No. 1) east of Mercury. Similar klippen are distributed over a distance of 120 km along north-trending axes of major synclines east of the Test Site. Regionally the direction of movement is toward the southeast, but local underthrusting, as in the CP hills, has resulted in some overturning of folds toward the west. The preponderance of evidence suggests that folding and thrusting occurred at moderate depths during Mesozoic time. Most of the thrust plates have been extensively sliced by strike-slip faults and by later normal faults during Tertiary time. Bus continues on to Mid Valley and turns around for return (6 km).

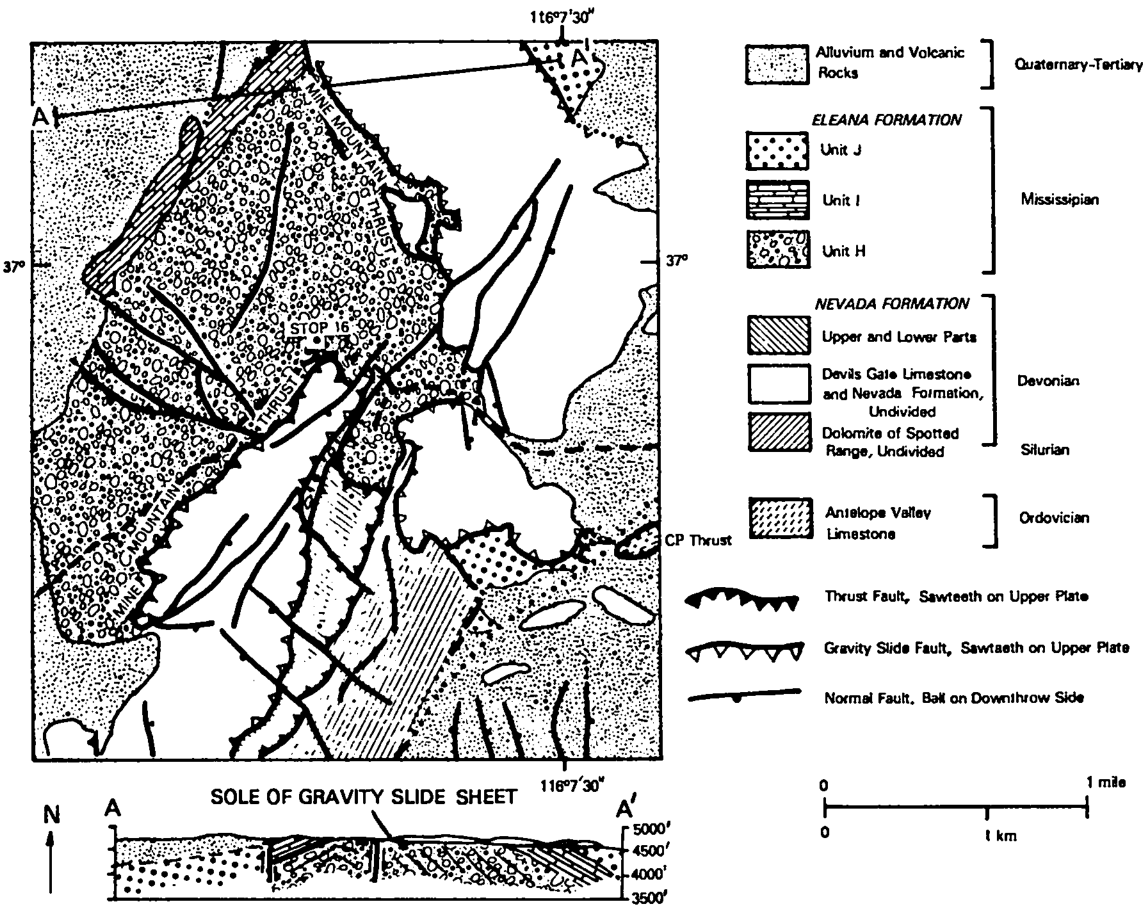

Fig. 21.
Geology in vicinity of Mine Mountain (Stop 16).

117.6 Turn right on Tippipah Highway for return to Mercury.

145.4 Exit NTS at main guard station in Mercury. Turn in badges, RAD-safe check. Return to Las Vegas. Hope you enjoyed the field trip.

ACKNOWLEDGMENTS

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