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FIELD TRIP TO NEVADA TEST SITE

Prepared By

U.S. Geological Survey

Open-File Report 76-313

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Prepared by the U.S. Geological Survey

for the

Nevada Operations Office
U.S. Energy Research and Development Administration
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and the

Defense Nuclear Agency

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards or nomenclature.

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ABSTRACT

Two road logs guide the reader through the geologic scene from Las Vegas to Mercury and from Mercury through eight stops on the Nevada Test Site. Maps and cross sections depict the geology and hydrology of the area. Included among the tables is one showing the stratigraphic units in the southwestern Nevada volcanic field and another that lists the geologic maps covering the Nevada Test Site and vicinity. The relation of the geologic environment to nuclear-explosion effects is alluded to in brief discussions of collapse, surface subsidence, and cratering resulting from underground nuclear explosions.

INTRODUCTION

This field guide has been prepared by the U.S. Geological Survey for use during field trips from Las Vegas to the NTS (Nevada Test Site) and during tours within NTS. A road log highlighting some major geologic features between Las Vegas and Mercury is followed by a general discussion of the geohydrology of NTS. The remainder of the field guide covers geologic and hydrologic features of interest at selected stops within the NTS.

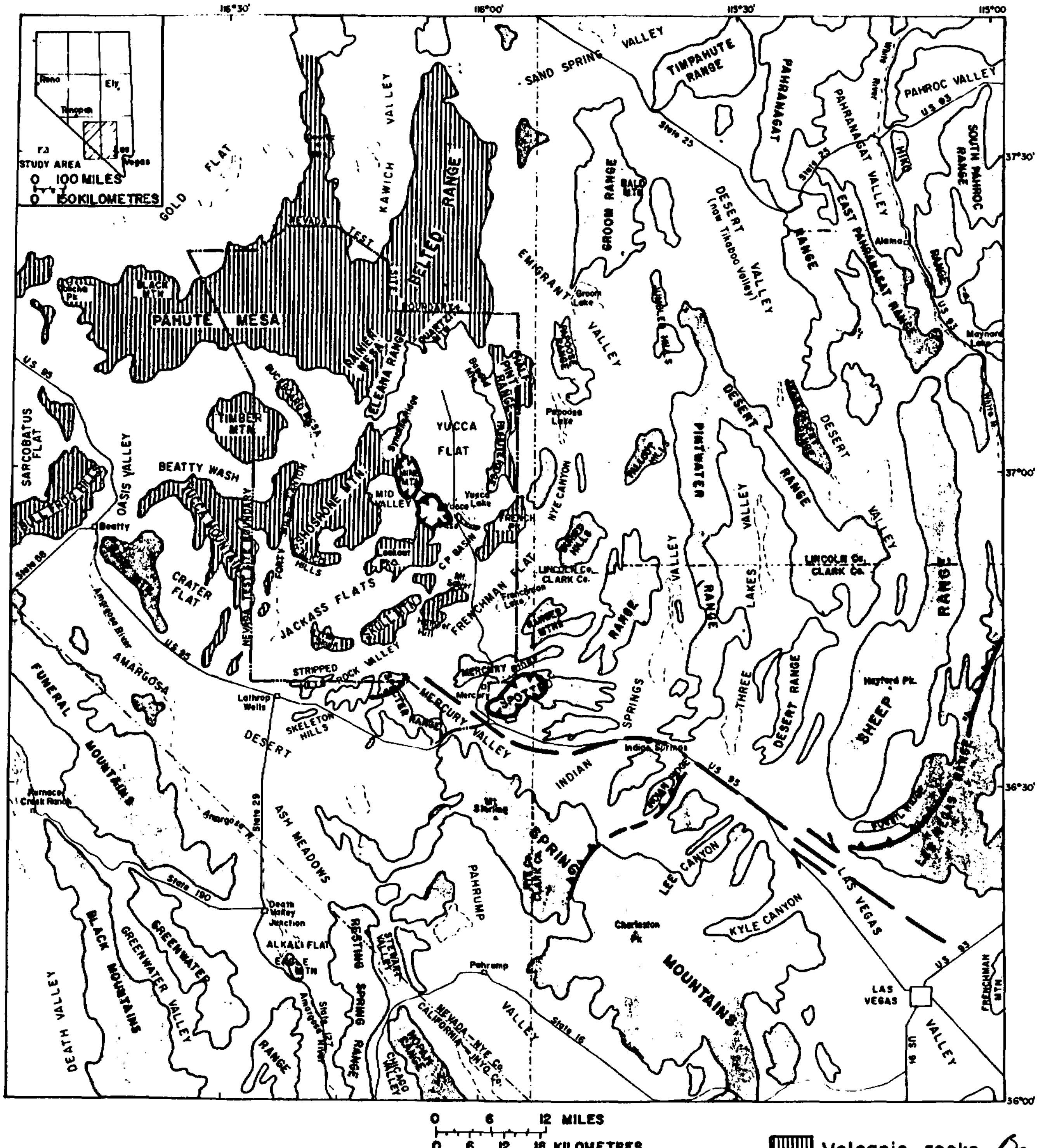
ACKNOWLEDGMENTS

Most of the brief writeups are synthesized from published reports, and from unpublished administrative reports and data. A selected bibliography is listed at the end of this field guide. The guide was edited and compiled by George S. Corchary and George A. Dinwiddie.

Colleagues, and their specialties, who also contributed to the guidebook are: Harley Barnes (Paleozoic rocks and structure), R. K. Blankennagel (hydrology), F. M. Byers, Jr. (volcanic rocks and petrology), W. J. Carr (volcanic rocks and structure), H. C. Claassen (hydrology, chemistry), G. S. Corchary (surficial deposits), G. A. Dinwiddie (hydrology), W. W. Dudley (hydrology), F. N. Houser (collapse, subsidence), P. P. Orkild (volcanic rocks and structure), and R. P. Snyder (surface effects).

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 Las Vegas Valley, which is the route of U.S. Highway 95 about 55 miles (89 km) from Las Vegas to the vicinity of Mercury, Nev. (fig. 1). The sharp bending or "drag" into the shear zone of major structural and topographic trends, as well as the offset across the shear zone of thrust faults, rock thicknesses, and rock facies demonstrate right-lateral movement along the zone. Stratigraphic and structural evidence indicates an aggregate right-lateral offset of 30-45 miles (48-72 km). Because the shear zone is covered by alluvium, the exact amount of strike-slip movement cannot be determined, but recent estimates range from 15 to 20 miles (24 to 32 km). The rest of the offset is attributed to structural bending or "drag." The age of strike-slip movement is now thought to be late Miocene to early Pliocene.



Volcanic rocks

Paleozoic rocks

Thrust fault

Las Vegas Valley Shear zone

Basalt about 10 M yrs

Base modified from U.S. Geological Survey 1°X2° topographic maps, 1969, 1970: Las Vegas (NJ 11-12), Caliente (NJ 11-9), Death Valley (NJ 11-11), and Goldfield (NH 11-8).

Figure 1.--Index map of the Nevada Test Site.

17000 ac ft / year / year at Ash Meadows

The area crossed on this field trip is in a belt of extensive thrust faults along the east side of the Cordilleran miogeosyncline. These thrust faults are of Mesozoic age and occur in the hinterland of the Sevier orogenic belt.

ROAD LOG: LAS VEGAS TO MERCURY

[Clock references indicate direction of feature from bus]

Distance mi (km)	Cumulative distance mi (km)	
0.0 (0.0)	0.0 (0.0)	Craig Road to right leads to Nellis AFB....continue straight ahead.
		Potosi Mountain at 8:30 o'clock is capped by Monte Cristo Limestone of Mississippian age. Prominent ridge between 8 and 9 o'clock is capped by Kaibab Limestone of Permian age. Wilson Cliffs, composed of buff and red Navajo (Aztec) Sandstone of Triassic and Jurassic age, between 8:30 and 9:30 o'clock, forms lower plate overridden by Keystone thrust. Narrow ridge at 9:30 o'clock is an erosional remnant of Keystone thrust; the ridge is capped by gray Goodsprings Dolomite of Cambrian and Ordovician age overlying red Navajo Sandstone. On La Madre Mountain, between 9:30 and 11 o'clock, are exposed carbonate rocks of Cambrian, Ordovician, Silurian(?), Devonian, Mississippian, Pennsylvanian, and Permian age. On Sheep Range, at 1 o'clock, the outcrops are rocks of Cambrian through

Distance mi (km)	Cumulative distance mi (km)	
		Mississippian age. On Las Vegas Range, between 1 and 3 o'clock, most outcrops are the Bird Spring Formation of Pennsylvanian and Permian age. Muddy Mountains are at 4 o'clock. Sunrise and Frenchman Mountains lie between 4:30 and 5:30 o'clock.
2.0 (3.2)	2.0 (3.2)	Ann Road to right....continue straight ahead.
2.4 (3.9)	4.4 (7.1)	Tule Spring Park Road to right....continue straight ahead.
0.5 (0.8)	4.9 (7.9)	Gravel borrow pit on right.
1.3 (2.1)	6.2 (10.0)	View of La Madre Mountain stratigraphy between 9 and 10 o'clock. 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 Dolomite are 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.

Distance mi (km)	Cumulative distance mi (km)	
1.3 (2.1)	7.5 (12.1)	Charleston Park Road (Nevada State Highway 39) on left follows Kyle Canyon into heart of Spring Mountains....continue straight ahead.
3.3 (5.3)	10.8 (17.4)	Rest area on right....continue straight ahead. Many of the geologic features exposed in the next few miles near the Lee Canyon Road (Nevada State Highway 52) are outlined on figure 2. 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 offer corroborative evidence of strike-slip movement.

To the northeast: The rocks of the Sheep Range are the typical thick miogeosynclinal section of eastern Nevada. The two prominent black bands are the lower member of the Ely Springs Dolomite repeated by faulting. Under the upper of the two black bands is the light-colored Eureka Quartzite. The Eureka is underlain by brownish-gray Pogonip Group carbonates, which in turn are underlain by the Nopah Formation, the top 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

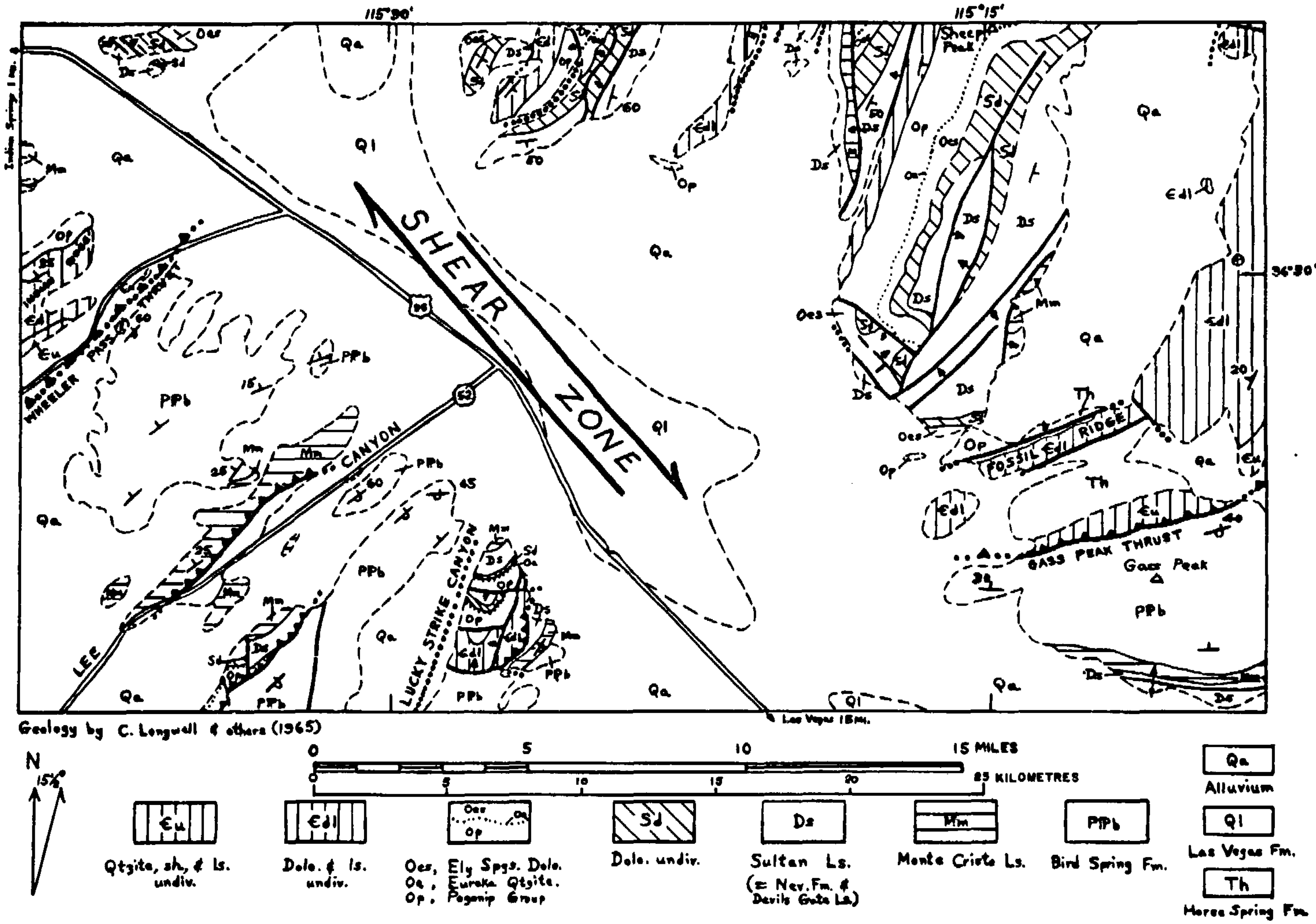


Figure 2.--Geology in vicinity of Lee Canyon, between Las Vegas and Mercury.

Distance mi (km)	Cumulative distance mi (km)	

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 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. 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 (Nevada Formation) of Devonian age. A thin light-gray dolomite separates the Eureka and Ironside. This dolomite contains the Ordovician Ely Springs Dolomite and possibly a very thin Silurian section. The Devils Gate Limestone forms the remainder of the ridge above the black Ironside (Nevada Formation). The Mississippian Monte Cristo Limestone forms the north-dipping slope of the main ridge and cannot be seen from here. The well-bedded outcrops north of Lucky Strike Canyon are the Bird Spring Formation. Below the Eureka in

Distance mi (km)	Cumulative distance mi (km)	
		the Lucky Strike Canyon section is gray and brown silty and clayey carbonate of the Pogonip Group. The black dolomite just above the valley fill is the upper part of the Nopah Formation.
		Fossil Ridge (fig. 2), on the right, is composed of Cambrian and Ordovician rocks. Gass Peak thrust, at 4:30 o'clock, separates upper plate of Cambrian rocks on left from lower plate of Pennsylvanian-Permian rocks of the Las Vegas Range on the right.
6.0 (9.7)	16.8 (27.0)	Lucky Strike Canyon Road to left. Road to right leads to Corn Creek Field Station of U.S. Fish and Wildlife Service which manages the Desert Game Range. Continue straight ahead.
0.7 (1.1)	17.5 (28.2)	Badland topography, at 3 o'clock, developed on Las Vegas Formation. These yellowish-gray lake beds have yielded fossil mollusks and mammals that indicate a Pleistocene date.
3.7 (6.0)	21.2 (34.1)	Lee Canyon Road (Nevada State Highway 52) on left....continue straight ahead. At 9 o'clock on skyline is Mummy Mountain. Corn Creek Range, at 3 o'clock, is composed of Cambrian and Ordovician strata. Desert Range, at 2 o'clock, is composed of Cambrian to Devonian strata.

Distance mi (km)	Cumulative distance mi (km)	
3.6 (5.8)	24.8 (39.9)	Playa of Three Lakes Valley is at 2 o'clock. Pintwater Range, at 1 o'clock, is composed of Cambrian to Devonian strata. Indian Ridge, at 10:30 o'clock, is composed of Cambrian and Ordovician rocks. Ridge, between 8 and 10 o'clock, is composed of Bird Spring Formation. The Wheeler Pass thrust probably separates these two ridges.
1.9 (3.1)	26.7 (43.0)	Camp Bonanza (Boy Scouts of America) and Cold Creek Road on left....continue straight ahead.
4.3 (6.9)	31.0 (50.0)	Southwest end of Pintwater Range, between 1 and 3 o'clock, is composed of Ordovician and Silurian-Devonian rocks. Ridge at 10 o'clock consists of gray cliffs of Monte Cristo Limestone and alternating brown silty and sandy limestone slopes and gray limestone of the Bird Spring Formation. Prominent high point on skyline ridge, at 9:30 o'clock, is Wheeler Peak.
2.1 (3.4)	33.1 (53.3)	Light-gray outcrop, at 3 o'clock, is mostly Devonian carbonate.
1.2 (1.9)	34.3 (55.2)	Village of Indian Springs. Indian Springs Valley is at 3 o'clock. White and brown outcrops in distance, at 1 o'clock, are Eureka Quartzite. Dark dolomite on ridge at 12:30 o'clock is Upper Cambrian Nopah Formation. Gray and brown outcrops forming prominent ridge south of village, 9 to 11 o'clock, are Bird Spring Formation.

Distance mi (km)	Cumulative distance mi (km)	
3.3 (5.3)	37.6 (60.5)	Village of Cactus Springs. Prominent black and white banded dolomite on ridge between 1 and 3 o'clock is upper part of Nopah Formation.
2.3 (3.7)	39.9 (64.2)	Prominent ridge on skyline between 9 and 12 o'clock is northwest end of Spring Mountains; Wheeler Peak is at 9:30 o'clock, Mount Stirling at 10:30
1.8 (2.9)	41.7 (67.1)	Road to right leads to test well 4.... continue straight ahead. Las Vegas Formation lake beds form yellowish-gray badland topography along highway.
3.2 (5.1)	44.9 (72.3)	Brown and gray outcrops immediately north of highway are Pogonip Group.
1.2 (1.9)	46.1 (74.2)	Same.
0.5 (0.8)	46.6 (75.0)	Gravel borrow pit at 3 o'clock.
0.8 (1.3)	47.4 (76.3)	Sign designating Nye-Clark County line (fig. 3). View of Spotted Range stratigraphy is between 12:30 and 4 o'clock. Rocks are typical thick miogeosynclinal strata similar to the Sheep Range section. They include Ordovician Pogonip Group limestone, Eureka Quartzite, Ely Springs Dolomite, Silurian dolomite, Devonian dolomite, Nevada Formation dolomite and quartzite, and Devils Gate Limestone (includes some dolomite and quartzite). Uppermost Devonian and Lower to Upper Mississippian rocks cannot be seen from here. Strata generally dip 30°-40°

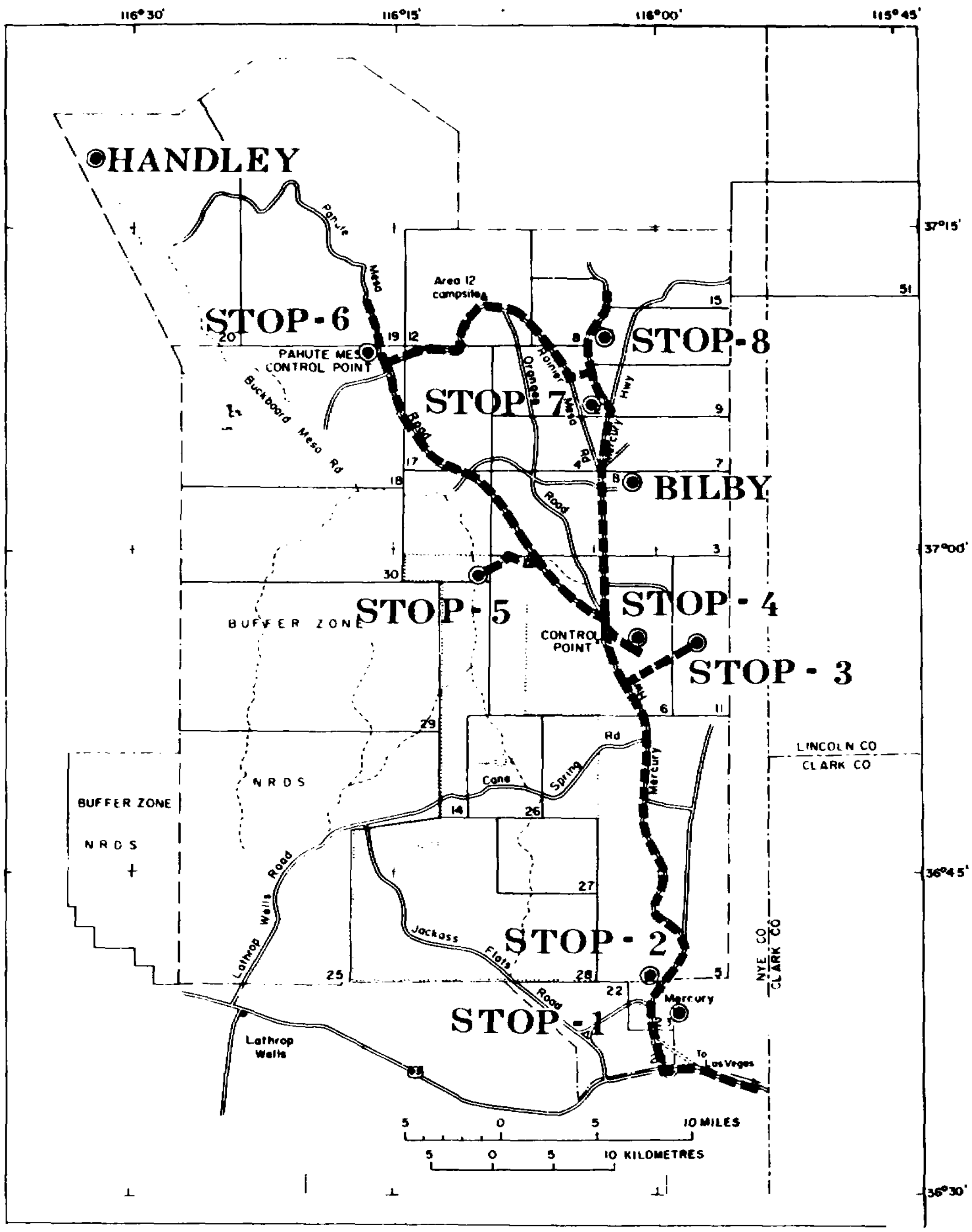


Figure 3.--Nevada Test Site showing stops to be made on the tour.

Distance mi (km)	Cumulative distance mi (km)	
		northwestward and form the southeast limb of the Spotted Range syncline. White quartzite part of the Eureka just above valley fill at 1:30 o'clock is overlain by black dolomite of the lower member of the Ely Springs. Ridge on skyline, between 12:30 and 2:30 o'clock, is South Ridge capped by Devils Gate Limestone; Spot Peak is at 2 o'clock. Nevada-Devils Gate contact on skyline at 1:30 o'clock. Prominent black band with brown slope-former below is the lower part of the Nevada Formation and can best be seen in middle part of range between 2 and 2:30 o'clock.
4.2 (6.8)	51.6 (83.0)	Massive gray cliffs at 3 o'clock are the *Palliseria*-bearing limestone in the middle part of the 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). Ridge on skyline between 11 and 1 o'clock is Specter Range. Skull Mountain, at 2 o'clock, is composed of volcanic rocks and is capped by black basalt flows.
1.5 (2.4)	53.1 (85.5)	Mercury interchange, bear right and follow Mercury Highway northward.

Distance mi (km)	Cumulative distance mi (km)	
1.0 (1.6)	54.1 (87.1)	Outcrops in foreground, at 3 o'clock, are Antelope Valley Limestone; hill with relay tower at 2 o'clock is Devils Gate Limestone. Red Mountain lies between 11 and 1 o'clock; the Specter Range lies between 7 and 10 o'clock.
1.4 (2.3)	55.5 (89.3)	Camp Desert Rock Road to left....continue straight ahead.
1.3 (2.1)	56.8 (91.4)	Badging and Security Offices on right. Stop at Badging Office to obtain badge permitting entry into NTS. Security officer at main entrance will check your badge.
0.2 (0.3)	57.0 (91.7)	Mercury Bypass Road to left....continue straight ahead.

ROAD LOG: MERCURY TO SEDAN CRATER

STOP NO. 1--MERCURY VICINITY

0.3 (0.5)	57.3 (92.2)	STOP NO. 1 (fig. 3). Park in large parking area to right of highway (fig. 4). View of Spotted Range and Specter Range geology. Red Mountain, between 9 and 12:30 o'clock, is composed of gray and brown Ordovician Antelope Valley Limestone on left through Eureka Quartzite, Ely Springs Dolomite, and Silurian dolomite on right. Strata on Red Mountain generally dip eastward. Mercury Ridge, between 1 and 2 o'clock, is composed mainly of Devonian Nevada

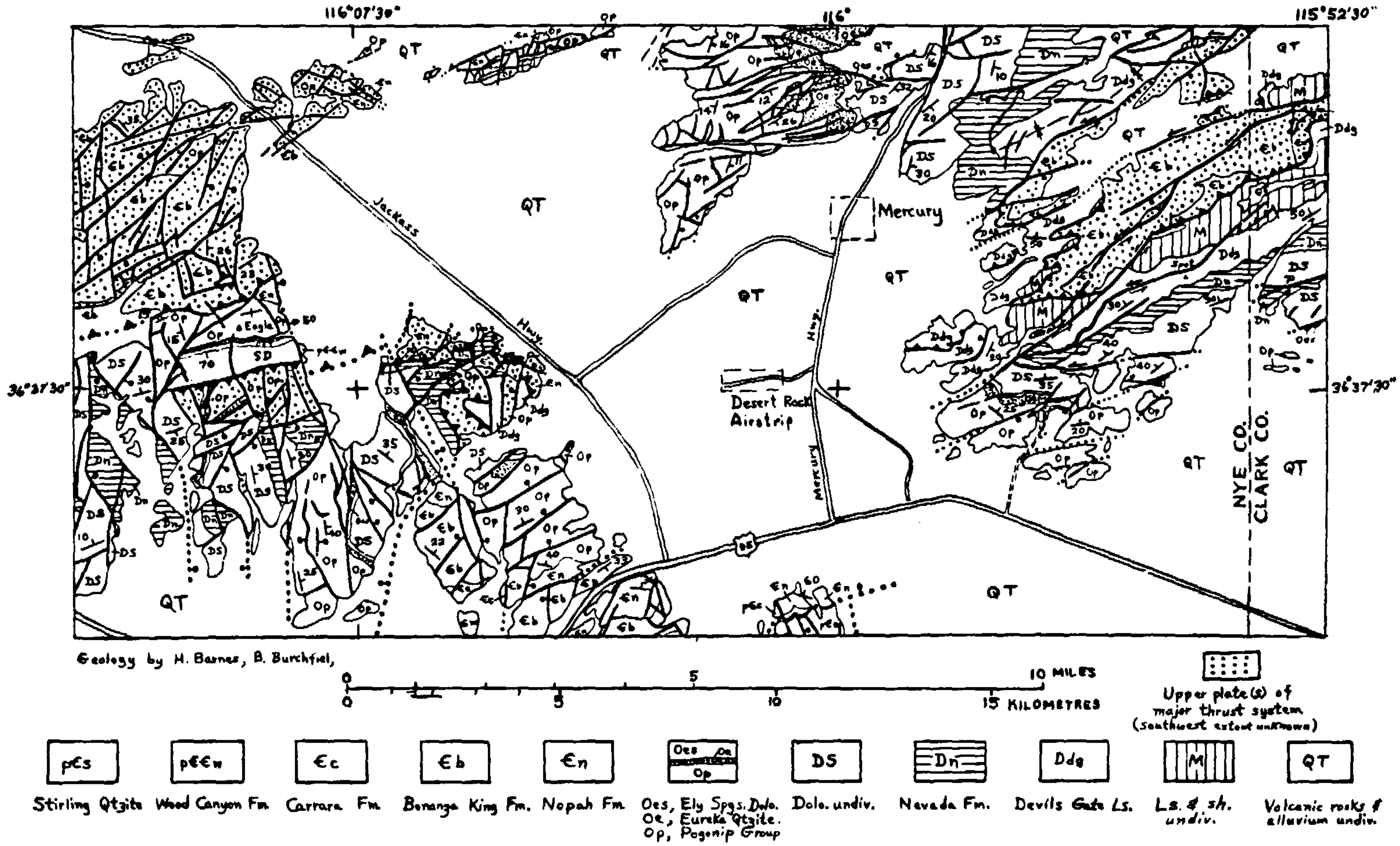


Figure 4.--Geology in vicinity of Mercury.

Distance mi (km)	Cumulative distance mi (km)	
		Formation and Devils Gate Limestone. North Ridge, between 2 and 3 o'clock, is composed of Middle and Upper Cambrian carbonates 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 o'clock consists of Ordovician through Mississippian rocks that form the southeast limb of the Spotted Range syncline. Tower Hills, at 4 o'clock, are Devils Gate Limestone. Specter Range, between 7 and 9 o'clock, contains Cambrian through Devonian rocks. Eagle Peak, at 8:30 o'clock, is composed of vertical strata of Antelope Valley Limestone; on left is stratigraphically higher white and brown Eureka Quartzite, black and gray Ely Springs Dolomite, and gray and black dolomite of Silurian age. To the right, just north of Eagle, a major thrust fault (Specter Range thrust) brings Upper Cambrian and Ordovician rocks over the Eagle Peak section--a structural situation similar to that mentioned 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 test site area.

NEVADA TEST SITE GEOHYDROLOGY--OVERVIEW

The NTS is the principal testing area for nuclear explosions. Since its inception in 1951 through 1969 there were 375 announced nuclear tests. Of these, 84 were in the atmosphere and 291 were underground. All but four of the atmospheric detonations occurred prior to the 1958 moratorium. Since 1962 the United States has conducted all of its nuclear detonations underground. The NTS, located about 70 miles (113 km) northwest of Las Vegas, encompasses 1,350 miles^2 (3,500 km^2) in the southern part of the Basin and Range province.

The NTS lies along the projected trend of the Walker Lane and the Las Vegas Valley shear zone. The shear zone, however, may not continue through the NTS in a simple way. The NTS is in a belt of late Mesozoic thrust faults along the eastern side of the Cordilleran miogeosyncline.

The eastern part of the NTS is characterized by the parallel Cenozoic topographic and structural elements generally associated with the Basin and Range province. The Quaternary basin-filling deposits and some of the Tertiary volcanic rocks of Yucca Flat and nearby areas are the principal media used for underground nuclear testing. Most nuclear detonations are made at Yucca Flat in the volcanic tuff that overlies the carbonate aquifer. Ground water in the tuff beneath Yucca Flat is slowly draining into the carbonate aquifer of Paleozoic age, but this downward movement is retarded by thick deposits of zeolitized tuff. Within the NTS, water moves southward and southwestward (fig. 5) through the carbonate to rocks beneath Yucca and Frenchman Flats, under Mercury Valley, to discharge areas in east-central Amargosa Desert. The quantity of water moving through the carbonate aquifer beneath Yucca Flat north of the playa probably is less than 350 acre feet per year ($43X10^4$ m^3/yr).

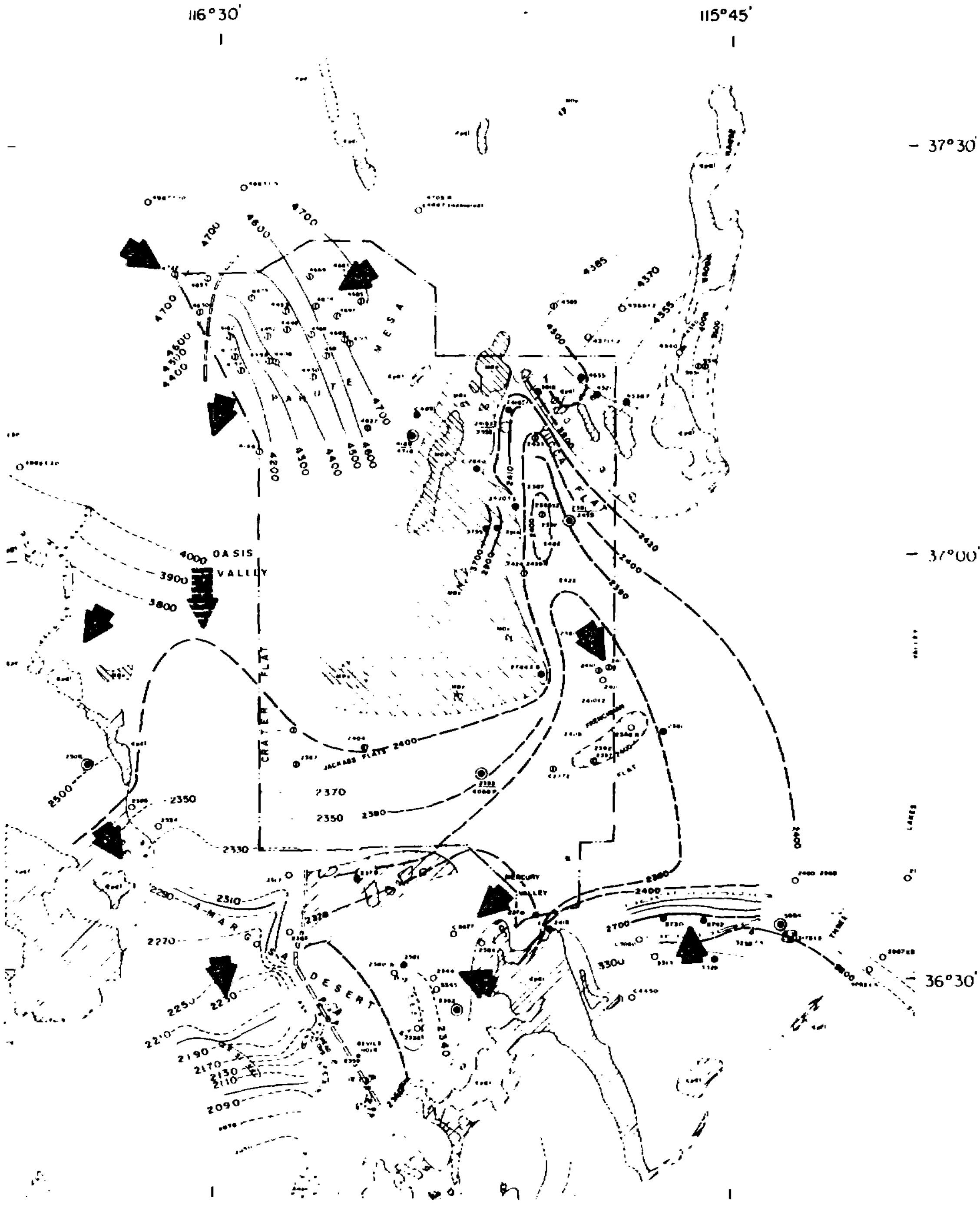


Figure 5.--Water-level contours, Nevada Test Site and vicinity.

The western part of the NTS was the locus of intense late Miocene and early Pliocene volcanism whose topographic and structural effects partly mask the more typical geologic features of the Basin and Range province. Ground water beneath Pahute Mesa, in the northwestern part of the NTS, moves generally southward under Oasis Valley, Crater Flat, and western Jackass Flats toward the Amargosa Desert. The quantity of water moving beneath Pahute Mesa is estimated at 8,000 acre feet per year ($985.5X10^4$ m^3/yr).

A continuous program of spring and well-water sampling from about 100 water-use points off the NTS has detected no radio activity in above-background concentrations moving in ground-water systems. The present water supply for all uses at the NTS is provided by several wells, which are monitored continuously. The closest well is 1,600 feet (488 m) from the nearest undergound test location.

STOP NO. 2--DATA CENTER--U.S. GEOLOGICAL SURVEY

The USGS (U.S. Geological Survey), at the request of the ERDA (U.S. Energy Research and Development Administration, formerally U.S. Atomic Energy Commission), acts as principal consultant for geologic data related to nuclear testing at NTS. To better implement that responsibility, the Geologic Data Center was established to collect, study, and codify all pertinent data.

Perhaps the most important data collection, and certainly the most obvious, is the vast library of rock samples. These samples range from hand specimens chipped from outcrops and tunnel walls, through drill-bit cuttings and sidewall plugs, to diamond-bit cores ranging in size from about 1 inch to 6 and even 8 inches (2.54 to 20.3 cm) in diameter. The core library currently houses core and cuttings representing nearly 2,000,000 feet (610,000 m) of drill hole. Between 750 and 1,200 boxes of samples, representing as much as 10,000-15,000 feet (3,050-4,570 m) of drill hole, may be logged into the library during a typical month of greatest activity.

In addition to the rock samples, a complete library of geophysical logs is also maintained. Records, comprising thousands of data cards, are kept to show all vital data pertaining to the rock samples, including dates, locations, laboratory tests performed, and final storage or disposition. An extensive reference library of publications, letters, memos, and maps that record geologic work performed at the test site is maintained as an aid to current and future work by Survey geologists. A hydrologic-chemical laboratory was established in 1966 to improve the handling of water samples for both chemical and radiological analyses.

Office space is provided for approximately 15 geologists and hydrologists, although the average daily population averages between five and seven persons. As many as 100 geologists, hydrologists, geophysicists, and technicians may work at the Data Center in a given year, for varying periods of time. Logistic support, such as vehicles, housing, and food service, is supplied by the ERDA through its prime contractor, the Reynolds Electrical and Engineering Company, Inc.

Participants in the NTS tour assemble at this stop and remain together for security reasons for the remainder of the trip. The buses will proceed north up the Mercury Highway to Checkpoint Pass (elev. 4,165± ft (1,270± m), which is flanked on both sides by brecciated and faulted Silurian dolomite. Emerge from canyon and continue descent into Frenchman Flat. View of Frenchman playa ahead (12 to 12:30 o'clock). Ranger Mountains, between 2 and 3 o'clock; are composed of Antelope Valley Limestone, Eureka Quartzite, Ely Springs Dolomite, dolomite of Spotted Range, and Nevada Formation. Aysees Peak, at 1 o'clock, in the Spotted Range consists of Ordovician rocks. Massachusetts Mountain at the southern end of Halfpint Range, between 11 and 1 o'clock, is composed of volcanic rocks. Low hills west of Frenchman Flat are composed of volcanic rocks.

STOP NO. 3--VOLCANIC ROCKS OF THE NEVADA TEST SITE

The southwestern Nevada volcanic field is a complex assemblage of rocks covering an area of several thousand square miles, mainly in southern Nye County. Most of these rocks are silicic ash-flow tuffs. The central area of the field is a faulted and dissected volcanic plateau of about 2,500 $miles^2$ (6,475 km^2) that extend northwestward from Yucca Flat. Several volcanic centers have been located in the southwestern Nevada volcanic field, and those associated with the large-volume ash-flow units generally are collapse calderas. Calderas in the immediate vicinity of the NTS include Silent Canyon caldera, the Timber Mountain caldera, and the Black Mountain caldera. Several other calderas in the surrounding region have been described by various investigators.

The Tertiary volcanic section of the southwestern Nevada volcanic field includes many units. One needs to be familiar with only a few of these units for the purposes of this trip, but table 1 lists all the major units of the NTS area for general reference. More detail of the Yucca Flat stratigraphy can be seen in figure 6. Major units related to the same volcanic centers and having close lithologic and petrographic similarities are named as formations; individual ash-flow cooling units (ignimbrites) are designated as members.

At this stop (fig. 7) we will climb over a stratigraphic section of the Timber Mountain Tuff and some underlying units at a place about 20 miles (32 km) southeast of Timber Mountain caldera, not far from the limit of the Timber Mountain Tuff in this direction. This will be the hardest walk of the day and will involve a climb of about 350 feet (107 m).

Table 1.--Major stratigraphic units of the southwestern Nevada volcanic field in the Nevada Test Site area

Unit	General lithology	Volcanic center
THIRSTY CANYON TUFF	Peralkaline ash-flow tuffs	Black Mountain caldera
Labyrinth Canyon Member		
Gold Flat Member		
Trail Ridge Member		
Spearhead Member		
TIMBER MOUNTAIN TUFF	Rhyolitic to quartz-latitic ash-flow tuffs	Timber Mountain caldera
Ammonia Tanks Member		
Rainier Mesa Member		
PAINTBRUSH TUFF	Rhyolitic to quartz-latitic ash-flow tuffs	Claim Canyon cauldron (Paintbrush cauldron on map)
Tiva Canyon Member		
Yucca Mountain Member		
Pah Canyon Member		
Topopah Spring Member		
WAHMONIE FORMATION SALYER FORMATION	Dacitic to rhyodacitic lavas, breccias, tuffs, and sandstones	Wahmonie Flat-Mt. Salyer
STOCKADE WASH TUFF	Calcalkalic rhyolitic ash-flow tuff	Silent Canyon caldera
BELTED RANGE TUFF	Peralkaline ash-flow tuffs	
Grouse Canyon Member		
Tub Spring Member		
CRATER FLAT TUFF REDROCK VALLEY TUFF	Low-silica rhyolitic ash-flow tuffs	Sleeping Butte caldera in north west part of Timber Mountain caldera complex
OLDER ASH-FLOW TUFFS	Rhyolitic to dacitic tuffs	North of Nevada Test Site

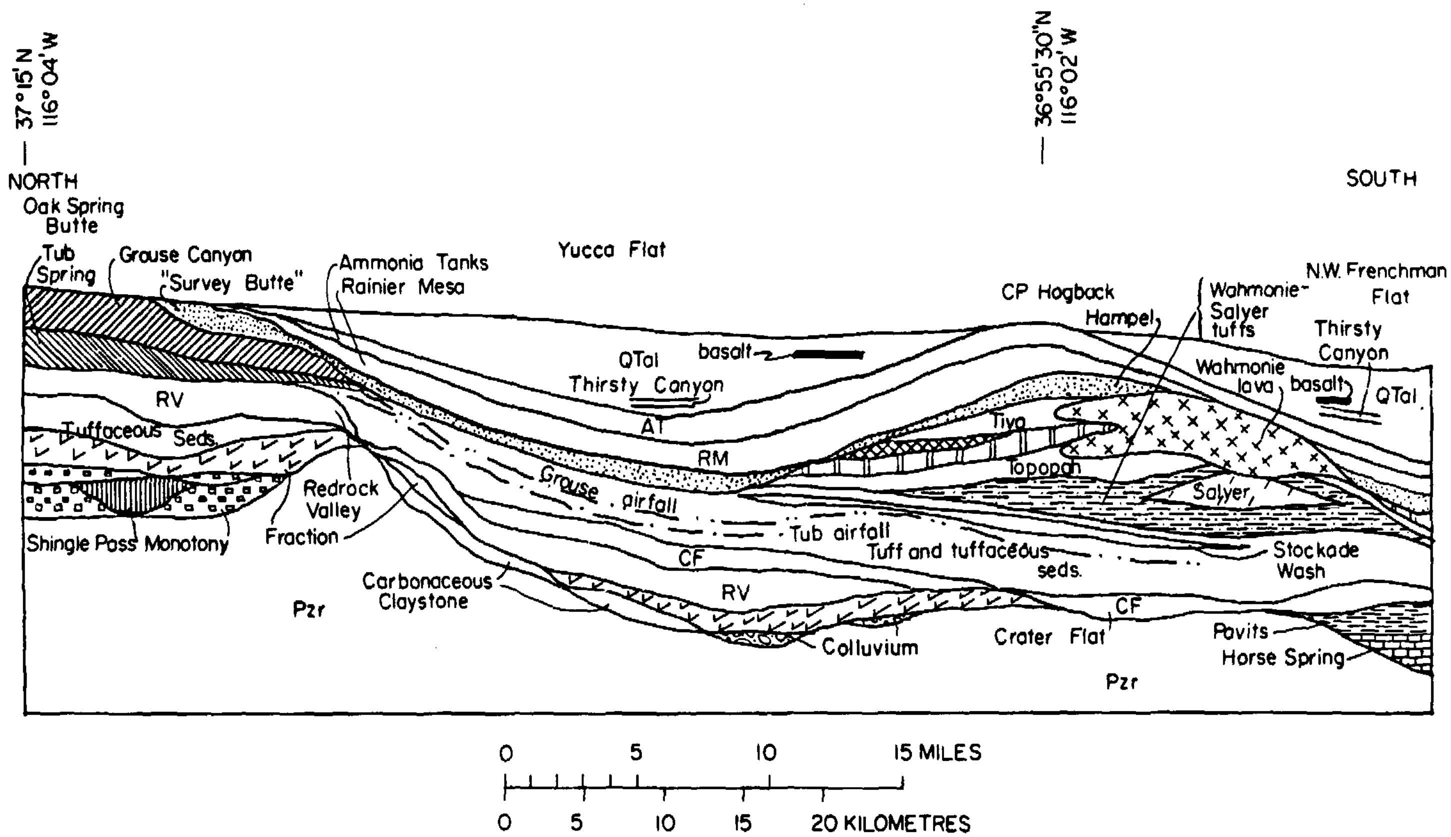


Figure 6.--Diagrammatic cross section from Oak Spring Butte to northwestern Frenchman Flat.

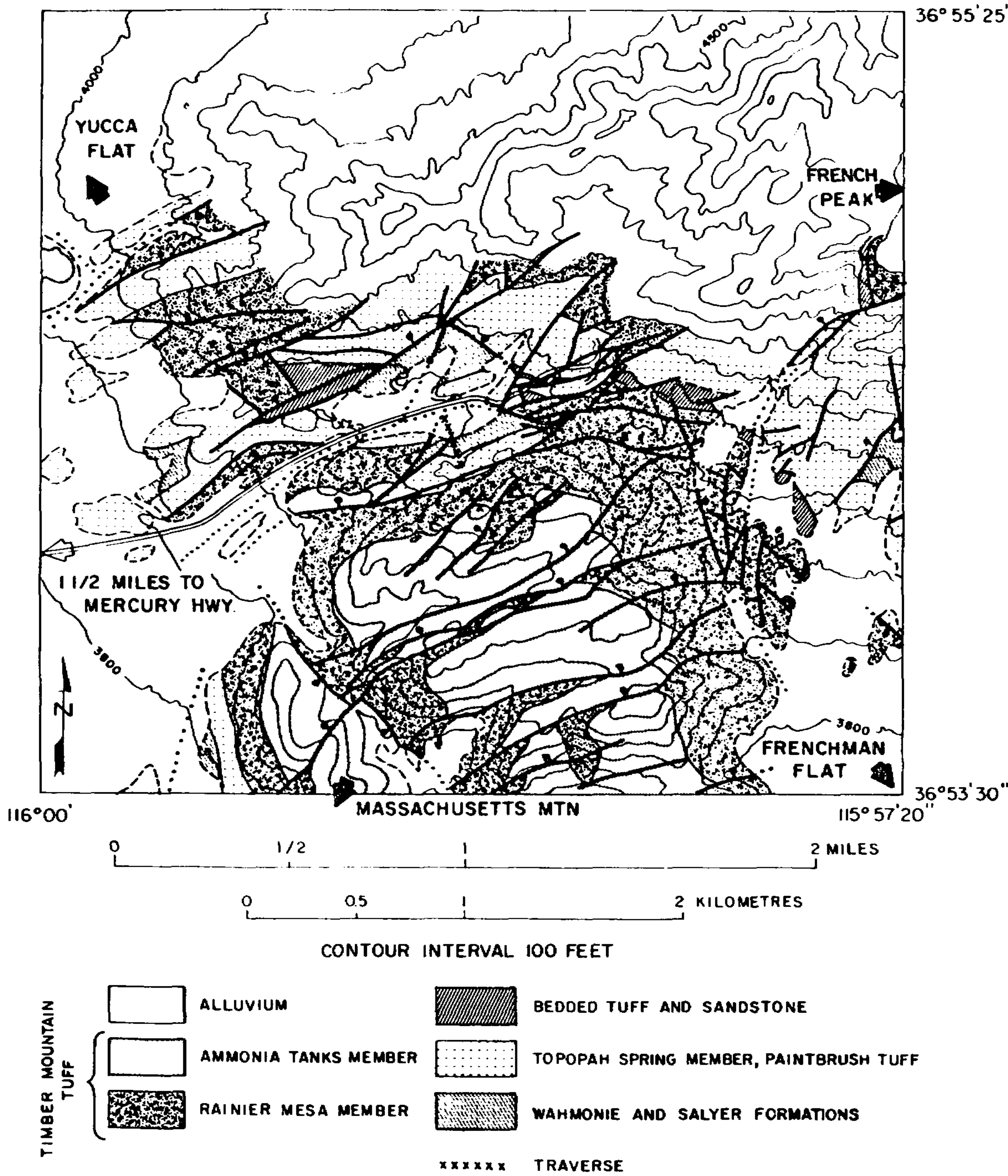


Figure 7.--Geologic map of an area between Yucca and Frenchman Flats.

At the base of the section, near the buses, we will cross a few outcrops of sandstone and tuff at the distal end of the Salyer-Wahmonie complex. We will then cross through the Topopah Spring Member of the Paintbrush Tuff in which we will see some of its typical welding and crystallization zones as well as a conspicuous compositional change, as shown by an upward increase in phenocryst content and proportion of biotite.

The base of the Rainier Mesa Member of the Timber Mountain Tuff is faulted against the upper Topopah Spring. We begin in the nonwelded glassy base of the Rainier Mesa, pass up through progressively more welded tuffs, encounter the contact of the divitrified zone, and climb through densely welded devitrified tuff. Above this we will see a vapor-phase zone and the nonwelded glassy top of the member. Thin ash-fall beds between the Rainier Mesa and Ammonia Tanks Members are covered where we will cross the contact. The Ammonia Tanks is thin and only partially welded at this place. It strongly resembles the Rainier Mesa, but with luck you may find a few crystals of sphene, a diagnostic accessory mineral present in the Ammonia Tanks but not in the Rainier Mesa.

Several criteria exist for distinguishing the Rainier Mesa and Ammonia Tanks, although many of them have only local significance and most of them probably will not be obvious to those newly acquainted with the area. It should be noted, however, that where field criteria fail, there are distinctive modal petrographic characteristics for each member. In addition, the Rainier Mesa has a natural remanent magnetization reversed to the Earth's present field, whereas the Ammonia Tanks has a normal natural remanent magnetization.

Although the volcanic section we will traverse at this stop is relatively unfaulted, the immediate area is one of the structurally most complicated at the NTS. It lies where the northeast-trending left-lateral Cane Spring fault zone intersects a northwest-trending right-lateral flexure and minor fault zone between

Yucca and Frenchman Flats. These two structural elements were concurrently active, and offset one another in a complex manner. Two small earthquakes at the NTS in recent years occurred along the right-lateral flexure zone near its intersection with left-lateral fault zones.

Retracing our stop 3 access route, the tour will continue north on the Mercury Highway toward Yucca Pass. From the highway, at 10 o'clock, is a window of Mississippian (brown) and Pennsylvanian (light-gray) rocks below the Cambrian (gray) rocks of the CP thrust. Brownish-weathering outcrops, at 11:30 o'clock, are Cambrian Carrara Formation. CP Hogback, between 12 and 3 o'clock, is composed of volcanic rocks. Two miles (3 km) farther is Yucca Pass (elev. 4,065± ft (1,240± m)). CP (Control Point) buildings on left. Continue straight ahead. Begin descent into Yucca Flat.

MERCURY WATER SUPPLY

Several air-burst tests were conducted in Frenchman Flat prior to the moratorium on nuclear testing in 1958. The north end of the valley has been developed as a test area for underground explosions since that time. The valley is underlain by playa deposits and alluvium, probably about 5,000 feet (1,524 m) deep in the center of the basin. Tertiary volcanic deposits are thick in the northern part of the valley, which marked the edge of the Tertiary volcanic basin, and are virtually absent on the south side.

Water supply for Mercury is obtained from Army Well 1--located on U.S. Highway 95 east of the junction to Jackass Flats--and from wells 5A, 5B, and 5C at Frenchman Flat. Water from Army Well 1 is pumped from Paleozoic carbonate aquifers; water from the wells in Frenchman Flat is obtained from valley fill and volcanic rocks. Water from wells in Frenchman Flat is of the sodium-potassium bicarbonate type; calcium-magnesium bicarbonate water is obtained from the Paleozoic carbonate aquifers in Army Well 1. A carbon-14 date of water from the valley-fill aquifer in Frenchman Flat suggests that the age of ground water in the tuff is probably in the range of several tens of thousands of years.

The altitude of land surface at well 5B is 3,092 feet (942 m); static water level is at a depth of 683 feet (208 m) below land surface. The specific capacity of the well, while pumping at a rate of 260 gal/min (1,420 m^3/d) is about 3.5 gal/min/ft (60 m^3/d/m). The well is cased to total depth of 900 feet (274 m) with 12-inch (305-mm) OD (outside diameter) casing from 0-460 feet (0-140 m) and 10-inch (254-mm) OD casing from 460 feet (140 m) to the total depth of 900 feet (274 m). The casing is perforated from 700-900 feet (213-274 m). Water from the three wells in Frenchman Flat is lifted 700 feet (213 m) vertically over Checkpoint Pass to Mercury via a system of pumping stations.

STOP NO. 4--YUCCA LAKE GEOLOGY

Yucca Lake, in the southern end of Yucca Flat, is a playa (fig. 8) having a nearly flat bed of fine-grained sediments. The playa surface has been much disturbed, including an aircraft landing strip, numerous bulldozed and plowed areas, and extensive lines of dikes, but perhaps the most conspicuous feature to be seen on its surface is a series of long concentric cracks in the southern end.

Desiccation cracks are a well-known feature of desert playas; most tend to be small, irregular or polygonal, and relatively narrow and shallow. A current study of large fractures in some local playas, and Yucca Lake playa in particular, suggests that they may not be due to desiccation for several reasons: (1) all the cracks of the type identified in this study trend generally N. 50° E.; (2) they tend to be linear rather than polygonal; (3) in Yucca Lake playa they trend at right angles to the gravity gradient and to the sides of the basin, contrary to what might be

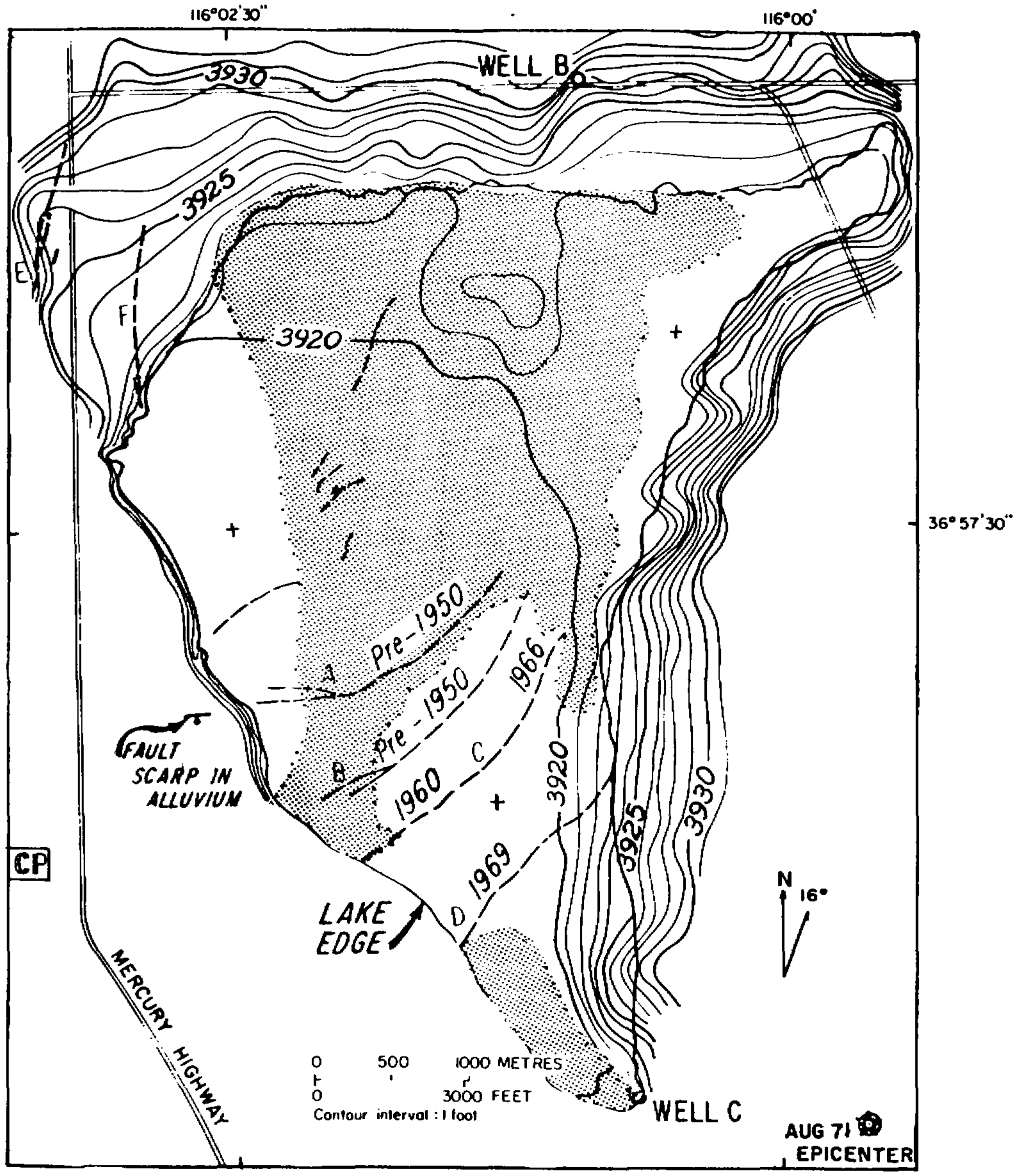


Figure 8.--Yucca Lake playa area showing cracks and detailed topography. Shaded area (-) is apparently depressed with respect to areas marked (+), based on distribution of water in the lake in March 1973; letters identify cracks referred to in text.

expected if they were due to shrinkage resulting from desiccation of the playa sediments; (4) at least one of the Yucca Lake playa cracks lines up with a small fault in the adjacent alluvium, which in turn trends toward a bedrock fault; (5) topographic data at hand for Yucca Lake playa indicate no subsidence has occurred in the immediate area of cracking; (6) water levels in wells B and C at the edge of the playa indicate no significant lowering of the water table during the last 10 years; and (7) large quantities of water flow into the cracks when they are new, indicating they may extend to considerable depth, possibly into rocks beneath the alluvium or into sandy or coarser materials in the basal alluvium.

Fractures inferred to be of tectonic origin are present in several playas of the region. Six fractures of this type are present on or near the surface of Yucca Lake playa. Four of these fractures (A-D on fig. 8) are subparallel and concave to the northwest; their trend varies from about N. 30° E. to N. 50° E. Two older cracks (E and F) beyond the northwest corner of the playa trend more northerly. The four parallel cracks in the southern part of the playa are about equally spaced and are younger from north to south. The youngest crack (D), still a prominent feature but filling rapidly, formed in 1969; the next crack to the north (C) formed in 1960 and was extended northeastward in 1966. On the basis of aerial photographs and degree of obliteration the third crack (B) probably formed prior to 1950. The fourth and northwesternmost crack (A) is older but of unknown age. None of these cracks shows obvious vertical offset, although the pattern of water distribution on the playa surface suggests that the area surrounding the younger cracks has been elevated slightly with respect to adjoining parts of the playa.

To further investigate the Yucca Lake playa cracks, elevations on a 1965 Holmes and Narver NTS map, scale 1:12,000, were contoured at 1-foot intervals. The area of the playa that contains the four parallel cracks was found to be nearly flat at the time the elevations were determined, except at the northeast end of the subsequent 1969 crack (D). Along the east flanks of the playa, contouring revealed a peculiar topography in positions approximating the northeastward projection of the three pre-1965 cracks. Whereas no detectable vertical offset occurred along the cracks on the playa itself, the near flanks of the playa may have subsided several feet along the projections of each of the cracks. An aerial photograph taken in March 1973 shows considerable water standing on the playa. Water extends all the way to the north edge of the playa, but the western edge of the playa and a large area around the youngest cracks (B, C, D) appear to be at or above water level. Thus, vertical changes of a foot or so may have taken place since 1964--another indication of tectonic adjustments of the playa surface.

The playa cracks in the NTS region vary somewhat in trend, but nearly all strike northeast. Details of geologic structure in the adjacent bedrock are available only for the cracks on Yucca and Frenchman playas. On Yucca Lake playa the major cracks have two distinctively different trends, suggesting that they may represent two different modes of failure. Both groups of fractures lie on the projection of the Yucca-Frenchman flexure, but the southern group of four curving cracks is nearly at right angles to the northwest trend of the flexure, suggesting that they could be conjugate shears. The two northerly trending cracks at the northwest corner of Yucca Lake playa could be extension cracks near the end of the shear and flexure zone, which appears to be dying out in that area. The curving cracks on Frenchman playa may have a similar origin and might be extension cracks at the opposite end of the Yucca-Frenchman shear and flexure zone.

YUCCA LAKE HYDROLOGY

Measurements in three water-supply wells, two (wells C and C-1) at the southern end of the playa and one (well 3) northwest of the playa, suggest that the depth to water beneath the playa is about 1,550 feet (457 m). The thickness of sediments and volcanic rock overlying the carbonate aquifer ranges from about 1,300 (396 m) to more than 1,800 feet (549 m) in the vicinity of the playa. The two southern wells, which are about 1,650 feet (503 m) deep, produce water from the carbonate aquifer; the northern well, which is 1,799 feet (548 m) deep and does not penetrate carbonate rocks, produces water from overlying strata of bedded and reworked tuff, sandstone, and conglomerate.

Old playa cracks, visible on aerial photographs, have been filled and sealed with fine-grained sediment. The cracks that split the playa in 1960 and again in 1969 are more than a mile long and, before enlargement by erosion and caving, were as much as several feet wide at the surface. Water on the playa pours into the open 1969 crack (D) at rates of several thousand gallons per minute after periods of moderate to intense precipitation. Observation of this phenomena and the ever-present need to understand the movement of water beneath Yucca Flat generated interest in studies of the cracks. Preliminary studies are underway to measure the amount and rate of inflow, to understand the development of future cracks, and to determine the physical and chemical characteristics of recharge, if any, to the saturated zone.

STOP NO. 5--MINE MOUNTAIN

The route to this stop (5) crosses the Mine Mountain thrust fault, which separates argillite of the Mississippian Eleana Formation in the lower plate from carbonate rocks of the Devonian Devils Gate Limestone and Nevada Formation in the upper plate (fig. 9, table 2). Overlook Point offers an excellent panorama of Mine Mountain thrust and of Yucca Flat.

Table 2.--Explanation of map symbols for figure 9

Symbol	Unit	Age
Qa	Alluvium	Quaternary
Tv	Volcanic rocks	Tertiary
	Eleana Formation	Tertiary
Mej	Unit J	Mississippian
Mei	Unit I	Mississippian
Meh	Unit H	Mississippian
Ddg	Devils Gate Limestone	Devonian
	Nevada Formation	Devonian
Dnu	Upper part	Devonian
Dnl	Lower part	Devonian
Ddn	Devils Gate Limestone and Nevada Formation, undivided	Devonian
	Dolomite of Spotted Range	Devonian
Duf	Unit F	Devonian
DSu	Dolomite of Spotted Range, undivided	Devonian, Silurian

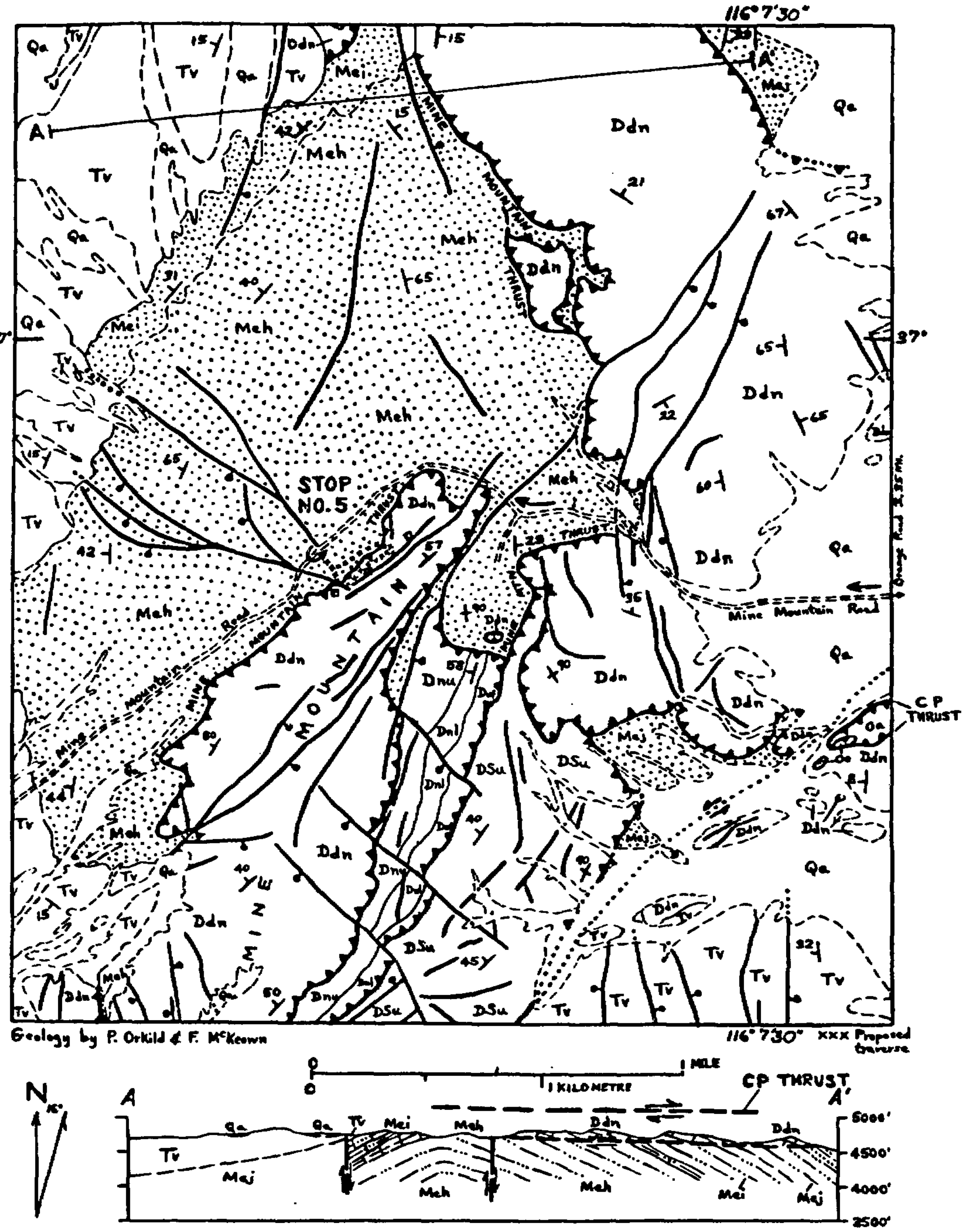


Figure 9.--Geology in vicinity of Mine Mountain.

Several thrust faults in the region of the NTS show 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 (pointed out from Stop No. 1) 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 75 miles (120.7 km) along north-trending axes of major synclines east of the test site. Regionally the direction of movement is toward the southeast but local under-thrusting, as in the CP Hills, has resulted in some overturning of folds toward the west. The preponderance of evidence suggests that folding, thrusting, and continued folding 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.

YUCCA FLAT HYDROLOGY

Most nuclear detonations are made at Yucca Flat in the volcanic tuff that overlies the carbonate aquifer (lower carbonate unit in table 3). A small proportion of the tests are conducted below the water table, which generally occurs in the tuff at depths of 1,500-1,800 feet (457-549 m). Laboratory analyses of cores indicate that ground-water velocity through the interstices of the tuff units to the underlying carbonate aquifer is less than 1 foot per year (0.3 m/yr). The velocity of ground water in the carbonate aquifer beneath central Yucca Flat is estimated to range from 7 to 700 feet (2-213 m) per year southward. Within the NTS, water moves southward and southwestward in the Paleozoic carbonate aquifer beneath Yucca (fig. 10) and Frenchman Flats, through Mercury Valley, to discharge at springs in Ash Meadows in east-central Amargosa Desert. The hydraulic gradient varies from 0.3 to 6 feet/mile (0.05-1 m/km). Interbasin movement through the

(p. 34a follows)

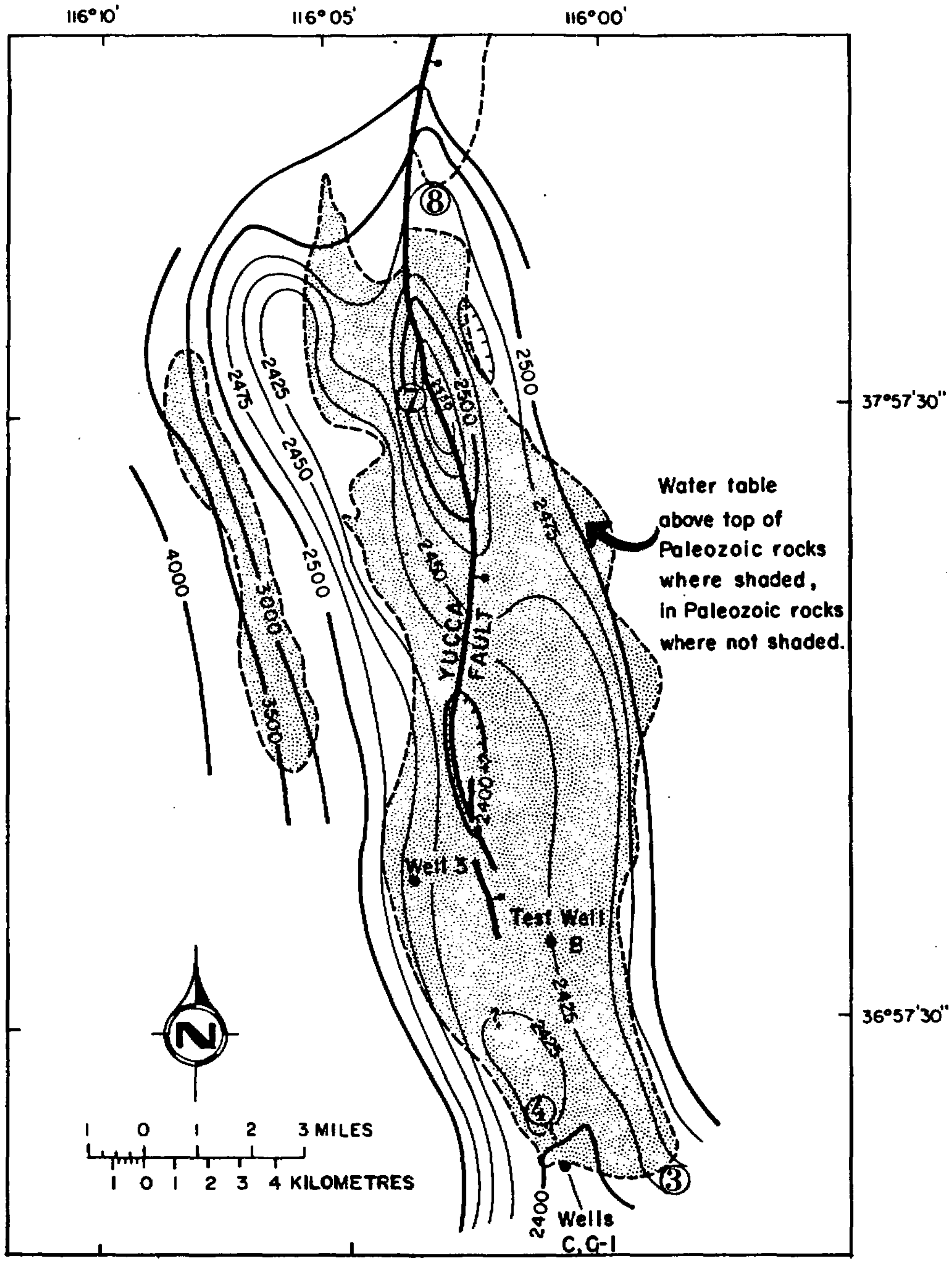


Figure 10.--Approximate altitude of water table beneath Yucca Flat. (Circled numbers 3, 4, 7, and 8 are tour stops.)

(p. 35 follows)

carbonate rocks is significantly controlled by geologic structure. In the vicinity of major structures, the lower carbonate aquifer is compartmentalized either by its juxtaposition against the less permeable lower or upper clastic units (table 3) along major normal or thrust faults, by the occurrence of the lower clastic unit in a structurally high position along major anticlines, or by gouge developed along major strike-slip faults. The water levels in the lower carbonate aquifer on opposite sides of such structures differ as much as 500 feet (152 m) in a single valley and as much as 2,000 feet (610 m) between valleys, although the hydraulic gradient within each aquifer compartment or block is only a few feet per mile. Ground-water studies on and near NTS show that major faults, such as the Las Vegas Valley shear zone south of NTS and a major fault near the western boundary of NTS at Pahute Mesa, commonly are barriers, rather than conduits, for normal ground-water flow. However, no faults are known to retard the southwestward flow of ground water along the path from Yucca Flat to the Ash Meadows discharge area. The lack of barriers is indicated also by the low hydraulic gradient, about 40 feet in a distance of 45 miles (12 m in 72 km). If the maximum flow rate (700 ft/yr (213 m/yr)) estimated to occur beneath Yucca Flat is applicable also to Frenchman Flat and Mercury Valley (fig. 5), contaminated water entering the carbonate aquifer in Yucca Flat would move offsite in about 145 years. Because these contaminants must first pass through the volcanic tuff, which has a low permeability and a great capacity for sorbing most radioactive ions, thousands of years is a more realistic estimate. Tritium, which would not be retarded by sorption, would still be reduced in concentration to far below existing health standards by radioactive decay and by dispersion during this time.

(p. 35a follows)

Table 3.--Pre-Cenozoic rocks exposed in and near Yucca Flat, Nevada Test Site

Age	Formation and approximate thickness, in feet (1 foot=0.305 metres)		Dominant lithology	Gross lithologic unit and thickness, in feet
Permian(?) and Pennsylvanian	Tippipah Limestone	(3,600)	limestone	Upper carbonate unit (3,600)
Mississippian and Devonian	Eleana Formation	(7,900)	argillite, quartzite	Upper clastic unit (7,900)
Devonian	Devils Gate Limestone	(1,380)	limestone	Lower carbonate unit (15,400)
	Nevada Formation	(1,525)	dolomite	
Devonian and Silurian	Dolomite of Spotted Range	(1,415)	dolomite	
Ordovician	Ely Springs Dolomite	(305)	dolomite	
	Eureka Quartzite	(340)	quartzite	
	Antelope Valley Formation (Pogonip Group)	1/ (1,530)	limestone	
	Ninemile Formation (Pogonip Group)	1/ (335)	siltstone	
	Goodwin Limestone (Pogonip Group)	(950)	limestone	
Cambrian	Nopah Formation	(2,010)	limestone, dolomite	
	Bonanza King Formation	(4,600)	limestone, dolomite	
	Carrara Formation	(1,000)	limestone	
		(1,000)	siltstone	Lower clastic unit (9,500+)
	Zabriskie Quartzite	2/ (220)	quartzite	
	Wood Canyon Formation	2/ (2,285)	quartzite, siltstone	
Precambrian	Stirling Quartzite	2/ (3,000)	quartzite	
	Johnnie Formation (base not exposed)	(3,000)	quartzite, limestone, dolomite	

1/ From the Ranger Mountains 2/ From the Groom Range

STOP NO. 6--TIMBER MOUNTAIN CALDERA

The Timber Mountain-Oasis Valley caldera complex (Timber Mountain caldera complex on the following map, fig. 11) occupies a slightly elliptical area about 25 miles (40 km) in maximum diameter in southern Nye County, Nev., and is a major part of the southwestern Nevada volcanic field, which includes peralkaline, alkali-calcic, calcalkalic, and calcic centers. Late Miocene and early Pliocene calcalkalic and alkali-calcic ash-flow sheets and petrologically related igneous rocks of the Timber Mountain-Oasis Valley caldera complex were erupted 16-9 m.y. ago and were associated with multiple cauldron subsidences.

The lower Pliocene alkali-calcic Timber Mountain Tuff includes all quartz-bearing ash-flow tuff sheets and minor interbedded ash-fall tuff erupted about 11 m.y. ago from the Timber Mountain caldera center. The tuff includes, in ascending order, the Rainier Mesa and Ammonia Tanks Members, which are the two widespread ash-flow sheets, and the intracaldera tuffs of Buttonhook Wash and Crooked Canyon.

Two major subsidences of Timber Mountain caldera occurred: the first associated with eruption of the Rainier Mesa Member, the second with the eruption of the Ammonia Tanks Member. These two units had a volume of more than 300 $miles^3$ (1,250 km^3), and about 230 $miles^3$ (950 km^3), respectively. The tuff of Cat Canyon, exposed on the central resurgent dome of Timber Mountain caldera, is intra-caldera Ammonia Tanks, more than 3,000 feet (914 m) thick. Thicknesses in excess of 1,500 feet (457 m), granophyric texture, and fluidal flow banding of both the Rainier Mesa and Ammonia Tanks Members within the Oasis Valley caldera segment (Oasis Valley volcanic depression on fig. 11) suggest partial collapse of that area during eruption of the members. The area that collapsed because of the eruption of the Rainier Mesa is somewhat larger than that which collapsed because of the Ammonia Tanks, as might be expected from the greater volume of the Rainier Mesa.

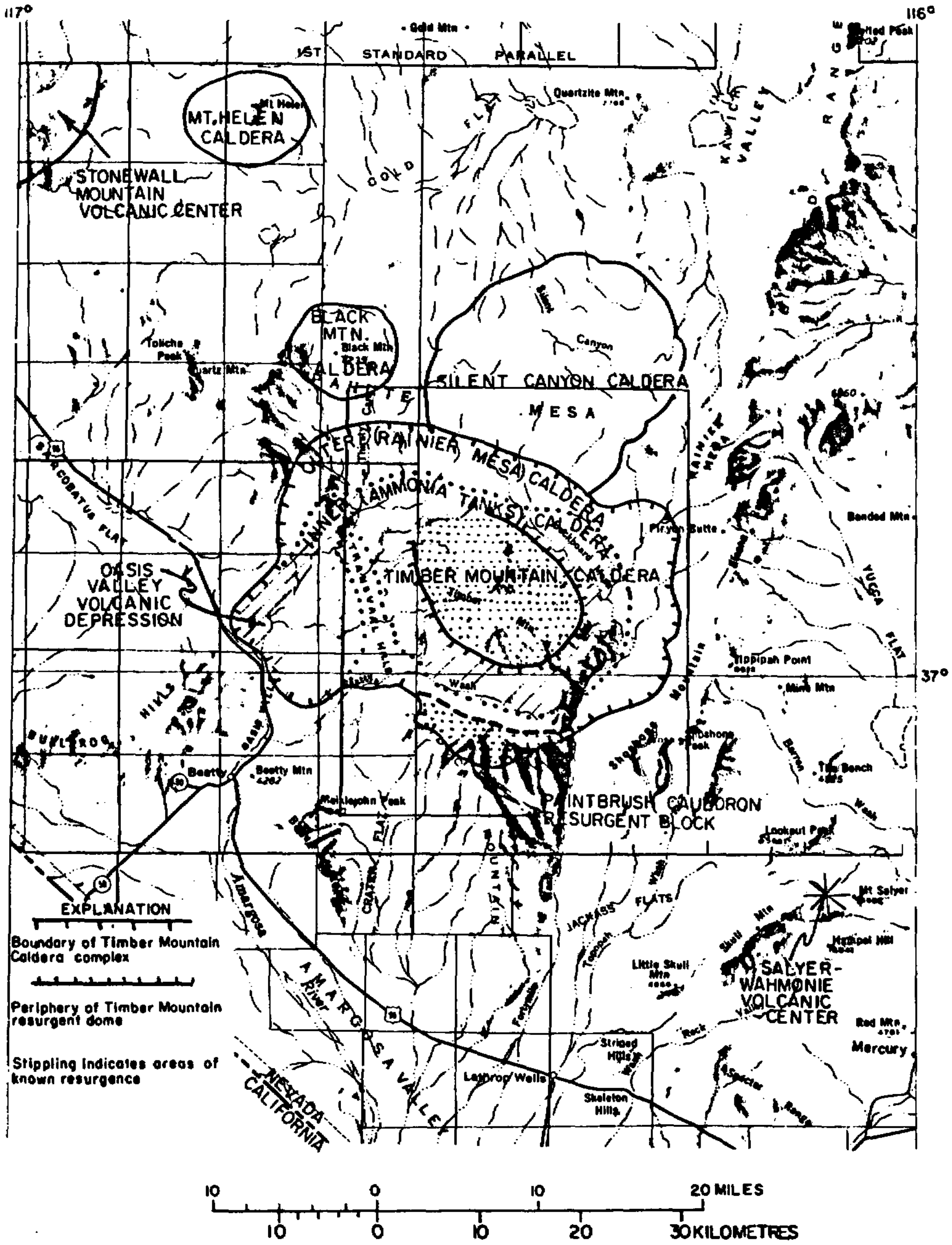


Figure 11.--Timber Mountain caldera complex and adjacent region, showing the location of major volcanic centers.

The Timber Mountain resurgent dome in the central area of Timber Mountain caldera contains both inward-dipping high-silica rhyolite tuff dikes, possibly cone sheets, and an outward-dipping micrograniitic ring dike that approaches quartz latite composition (68 percent silica). These two rock types are petrologically similar to limiting compositions of the Ammonia Tanks Member and may have come from different levels of a zoned silicic magma chamber high in the crust.

Post-Timber Mountain alkali-calcic tuffs and related lavas are confined to the Oasis Valley-Timber Mountain caldera complex and probably were erupted 11.0-9.5 m.y. ago from within the Oasis Valley caldera segment. Rhyolite lavas extruded from the rim and moat areas of Timber Mountain caldera concluded the activity of the caldera complex about 9 m.y. ago. Schematic diagrams illustrating the sequence of volcanic events in the Timber Mountain-Oasis Valley area are shown on figure 12.

At stop 6 (fig. 13), we will walk up on the low Ammonia Tanks hogback west of the road to view Timber Mountain caldera. The wall, rim, and moat are visible on the north, east, and southwest sides of the caldera; the central dome is at a distance of about 7 miles (11.3 km) west-southwest. The Ammonia Tanks Member of the Timber Mountain Tuff is present inside the caldera and forms the hogbacks, which onlap debris flows at the base of the wall.

PAHUTE MESA HYDROLOGY

Exploratory drilling in the Silent Canyon caldera, a deep structural depression, revealed a Tertiary volcanic section of ash-flow and ash-fall tuffs and rhyolitic lava flows which attained thicknesses in excess of 13,686 feet (4,171 m). Hydraulic tests made in deep drill holes indicated that these volcanic rocks were capable of transmitting water, and that measurable permeability occurred at depths greater than 3,500 feet (1,067 m) below the top

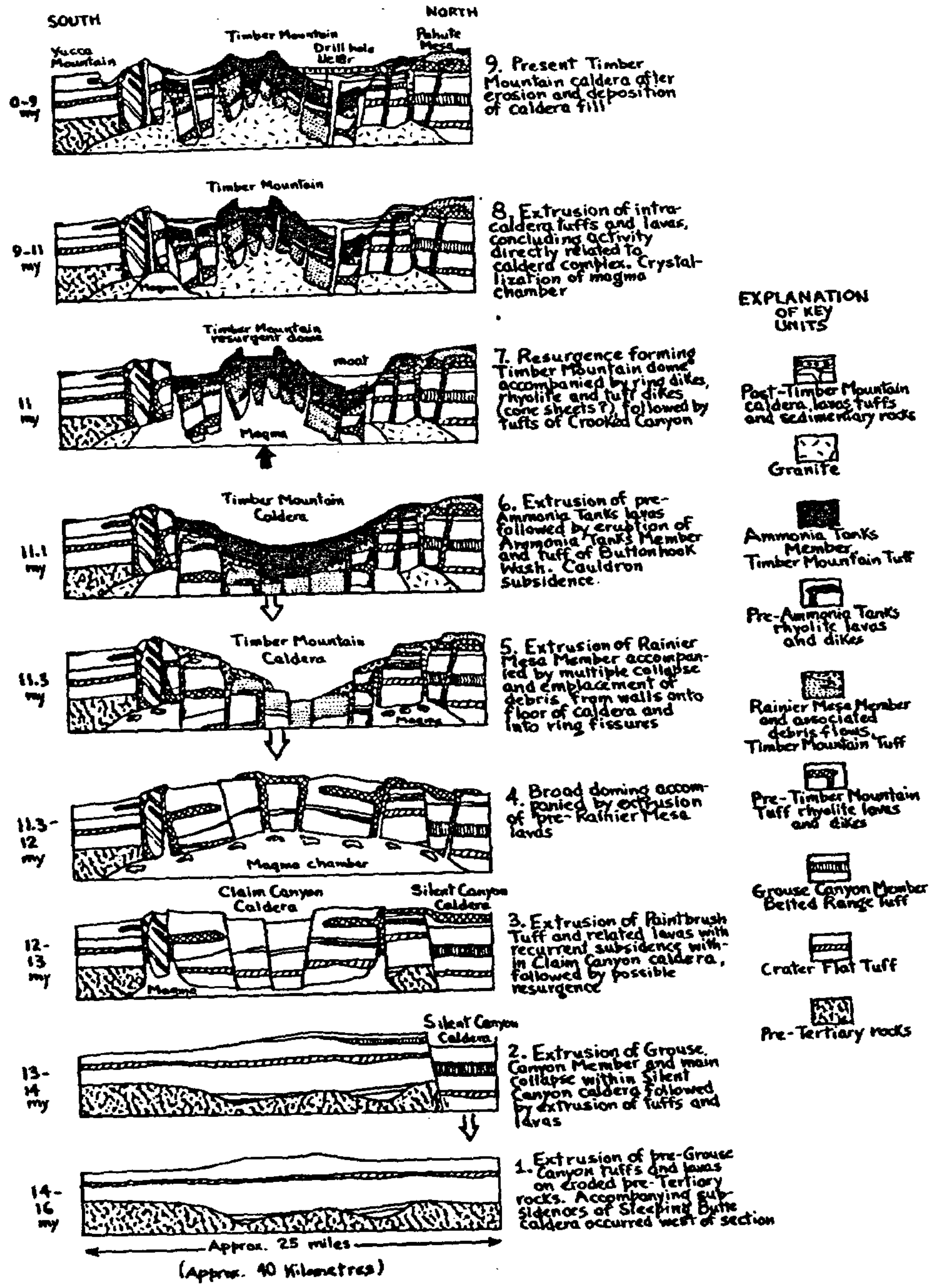


Figure 12.--Sequence of diagrams illustrating volcanic history of the Timber Mountain-Oasis Valley caldera complex.

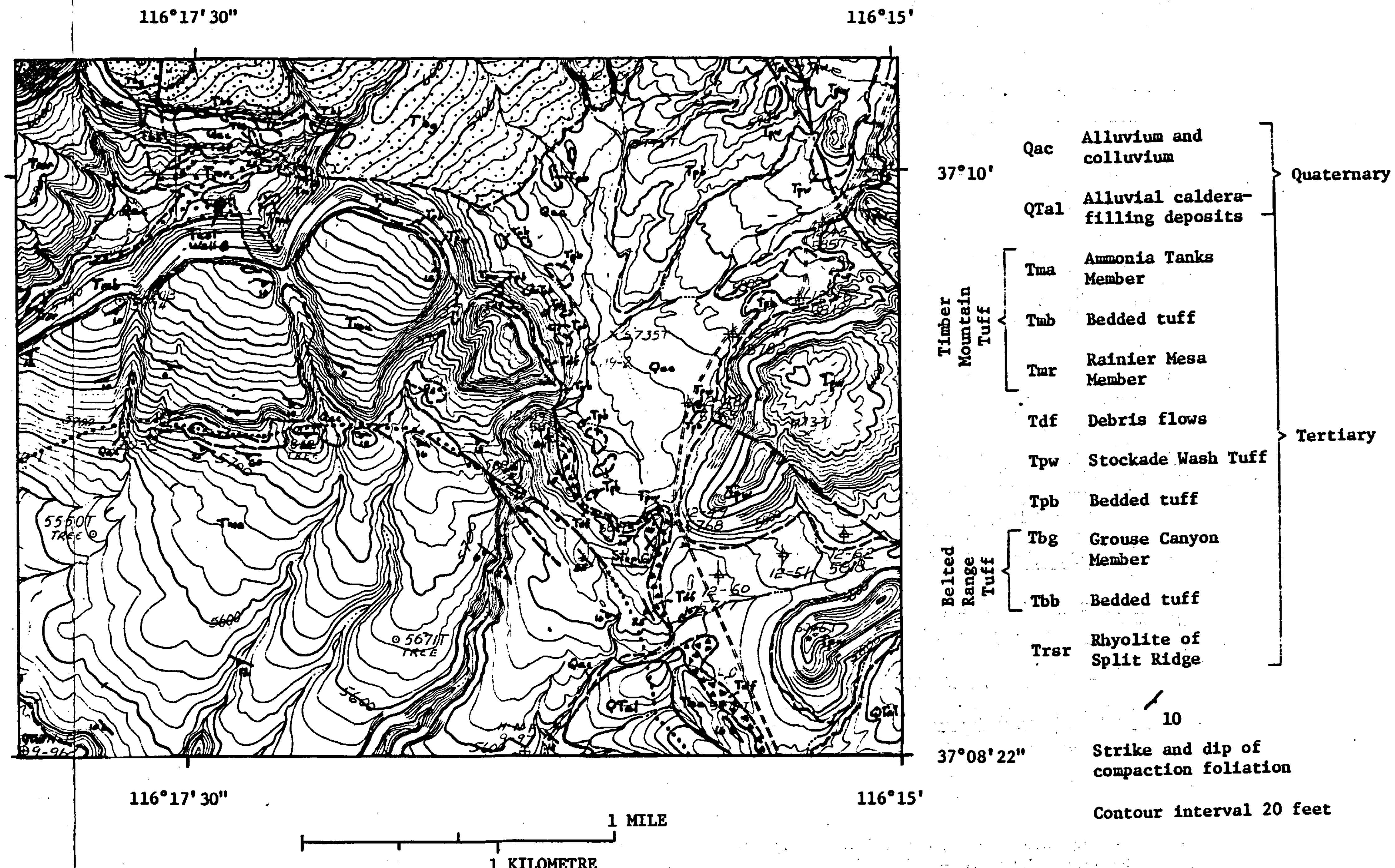


Figure 13.--Geology in the vicinity of the northeast scallop of the Timber Mountain caldera wall.

of the saturated zone. Depth to water ranges from about 1,952 feet (595 m) at an altitude of 4,164 feet (1,269 m) in the western part to 2,350 feet (716 m) at an altitude of 4,685 feet (1,428 m) in the eastern part. In the extreme northwestern part of the NTS, outside the caldera, the depth to water is about 850 feet (259 m) at an altitude of 4,700 feet (1,433 m).

Head decreases with depth in all but one of the holes drilled in the eastern part of the Pahute Mesa area, and head generally increases with depth in holes drilled deeper than 3,500 feet (1,067 m) in the western part (fig. 14). Transmissivities, based on single-well pumping tests, range from 1,400 to more than 100,000 gallons per day per foot (17 to 1,200 m^2/d). The greatest transmissivities occur in holes drilled along the eastern margin of the caldera where the principal rock type in the saturated zone is rhyolite (fig. 15). Water derived from drill holes at Pahute Mesa is the sodium potassium type. These chemical constituents are in excess of 90 percent of the cations in more than half the samples that were analyzed.

Most movement of ground water beneath the mesa occurs through interconnecting fault and joint systems. Fractures are common in rhyolitic lava flows and in densely welded ash-flow tuffs, and these fractures have a greater tendency to remain open than do those in ash-fall and nonwelded ash-flow tuffs. The yield of water to wells from intervals of ash-fall and nonwelded ash-flow tuffs, particularly those that are zeolitized or argillized, is low. Hence, these rocks are considered the best media for mining of underground chambers in the saturated zone.

Ground water beneath Pahute Mesa moves generally southward (fig. 16) toward the Amargosa Desert through Oasis Valley, Crater Flat, and western Jackass Flats. The quantity of water moving beneath Pahute Mesa is estimated at 8,000 acre-feet per year (1,000 ha-m/yr). The magnitude of effective fracture porosity,

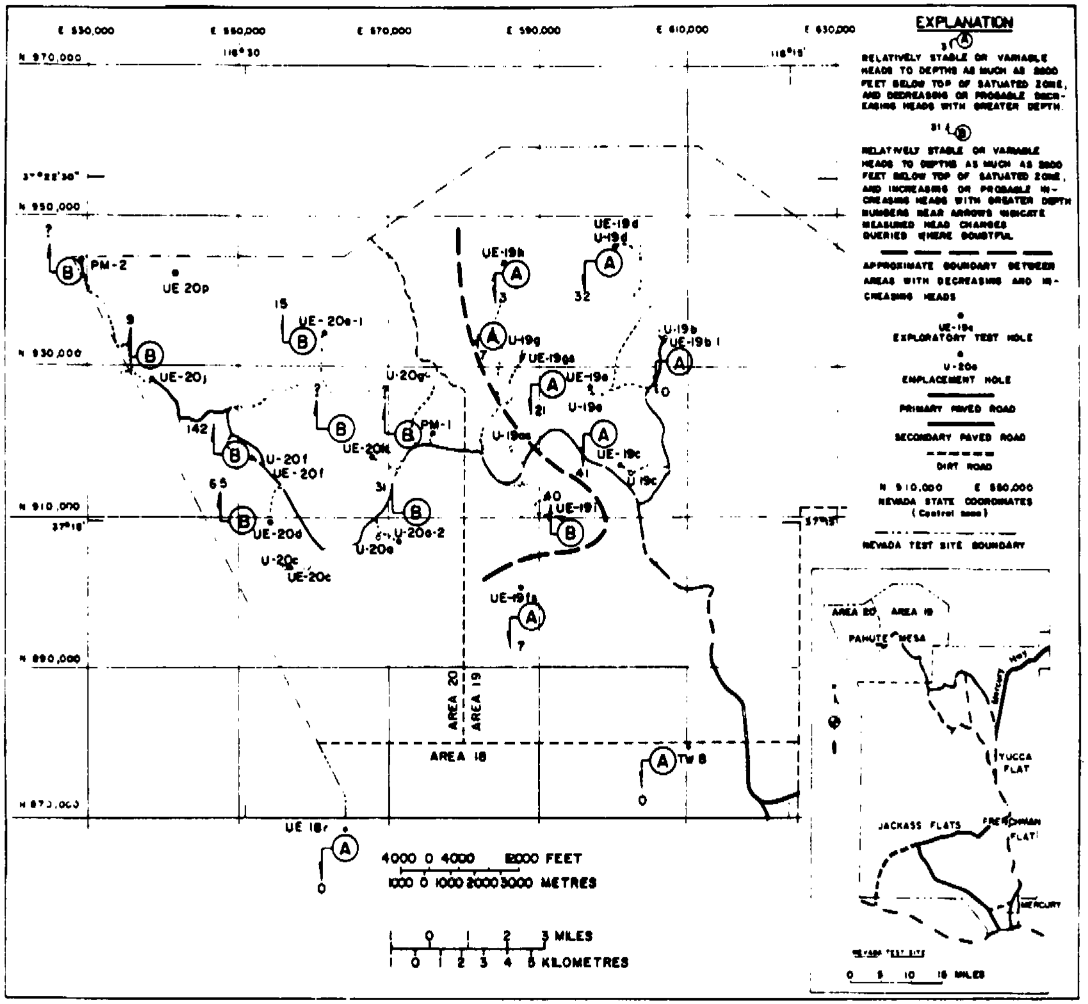


Figure 14.--Location of exploratory test holes in which hydraulic head changes with depth are recorded, Pahute Mesa.

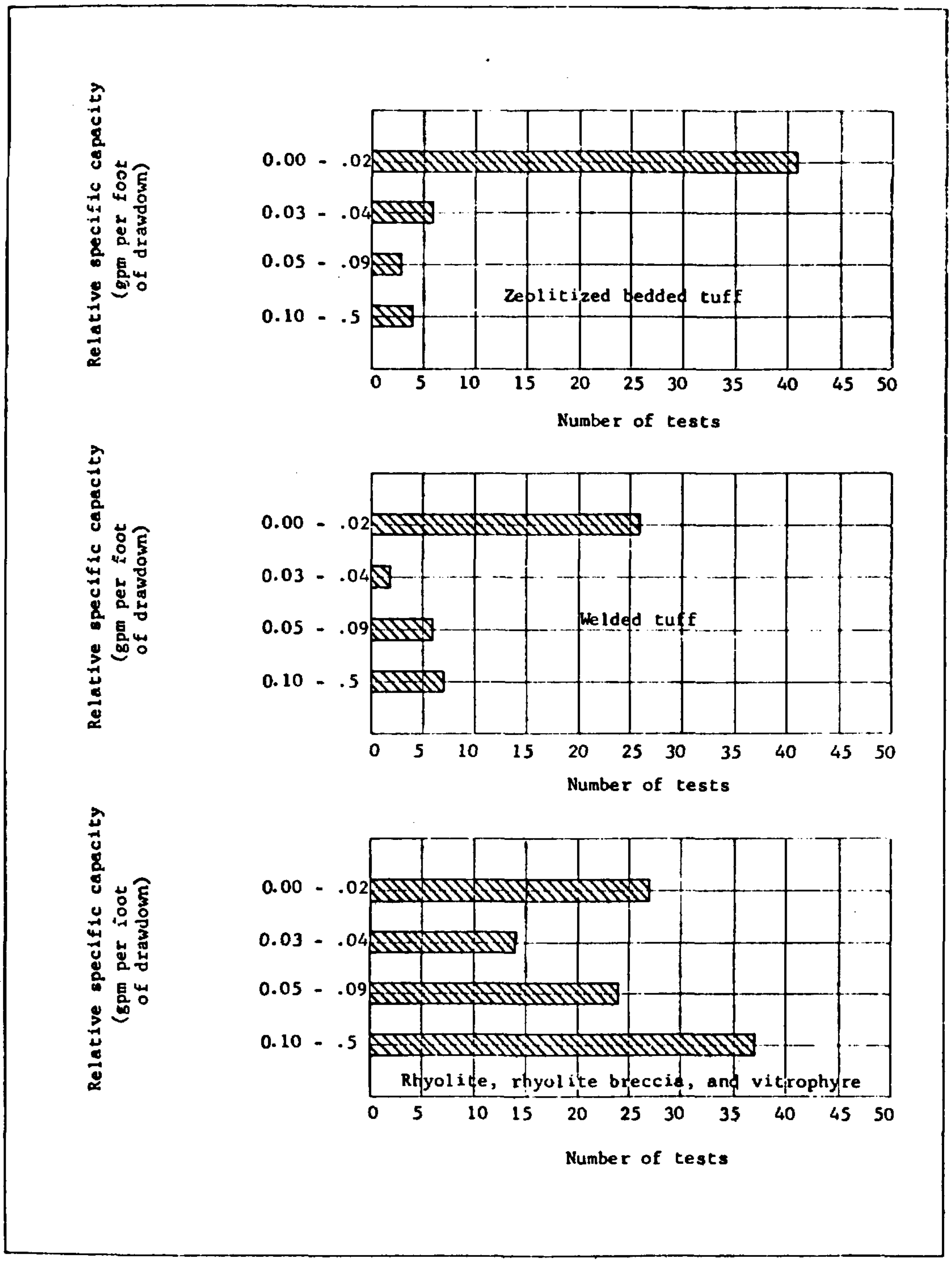


Figure 15.--Relative specific capacity (150- to 200-foot intervals) of the major rock types within the saturated zone, Pahute Mesa.

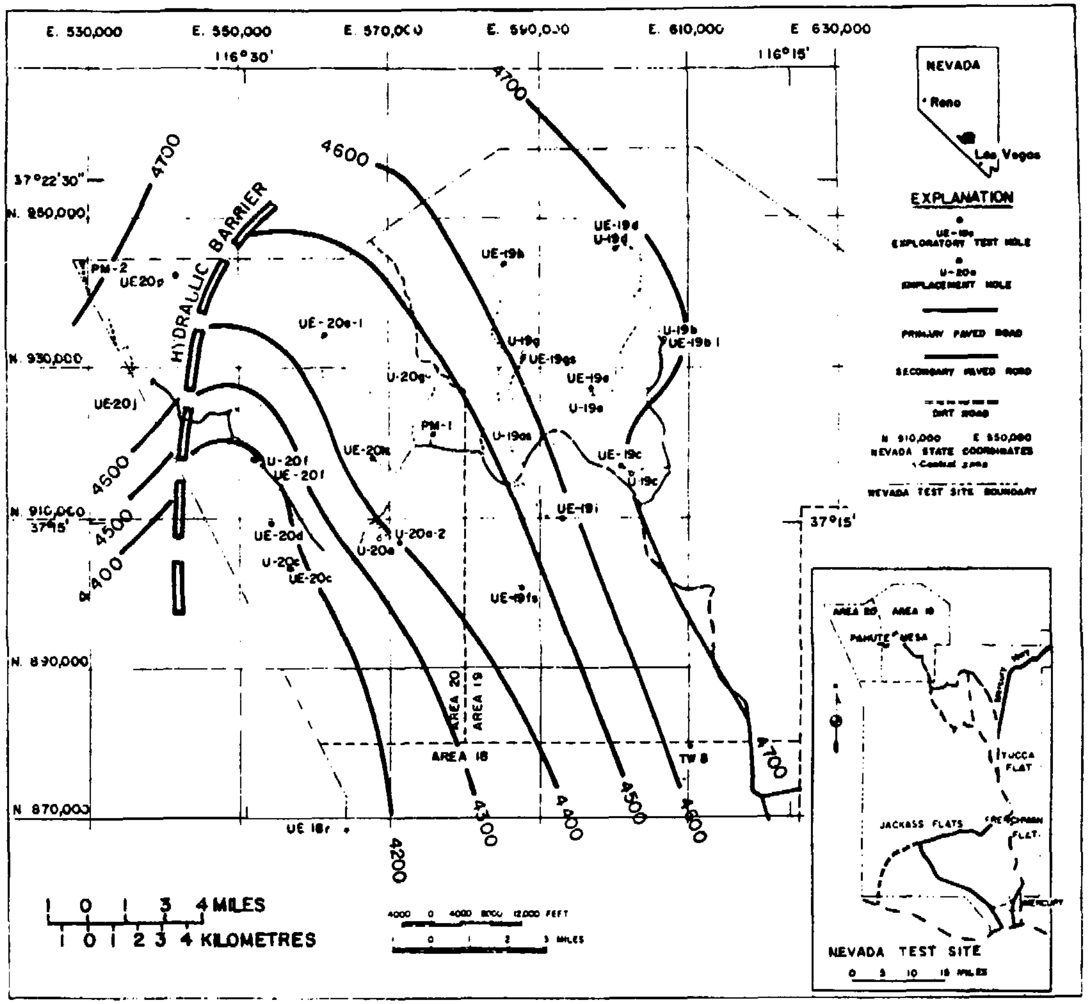


Figure 16.--Water-level contours and the line of the hydraulic barrier at Pahute Mesa.

a controlling factor of velocity of ground-water movement, is difficult to estimate for the heterogeneous volcanic rocks. Effective porosity was estimated to range from 0.5 to 20 percent for purposes of velocity calculations. The resulting estimated velocities beneath the mesa range from 7 to 250 feet per year (2 to 76 m/yr). Low permeability blocks between fractures probably result in velocities that vary as much as two or three orders of magnitude over short distances. A mean velocity corresponding to a porosity of 10 percent probably is the most acceptable value, assuming that most ground-water movement occurs along interconnected fractures but some occurs through interstices. Computations using this value of porosity would yield a mean velocity of approximately 15 feet per year (5 m/yr).

HYDRAULIC EFFECTS OF EXPLOSIONS

Fluid-pressure response to several nuclear events in the last decade has been measured by placing pressure transducers in boreholes, often with the water column confined by inflatable packers. The first effect is an oscillatory pressure response to seismic signals generated by the explosion. The Handley event, an explosion having a yield slightly greater than 1 megaton, produced a dynamic ground-water overpressure of more than 300 feet (90 m) in drill hole UE20f (fig. 17), about 3 miles (5 km) from the event site. In Clayton Valley, 71 miles (115 km) northwest of the Handley site, the oscillatory head change was less than 3 feet (1 m) but produced surges of more than 100 gpm (550 m^3/d) in some open wells.

Sustained pressure changes, resulting from compaction of the rocks around the explosion and from closing of fractures by seismic stresses, were recorded for more than a month after the Handley event. In drill hole UE20p (figs. 17-18), about 3 miles (5 km) north of the event site, a sustained pressure rise of 164 feet (50 m) occurred 4 days after Handley.

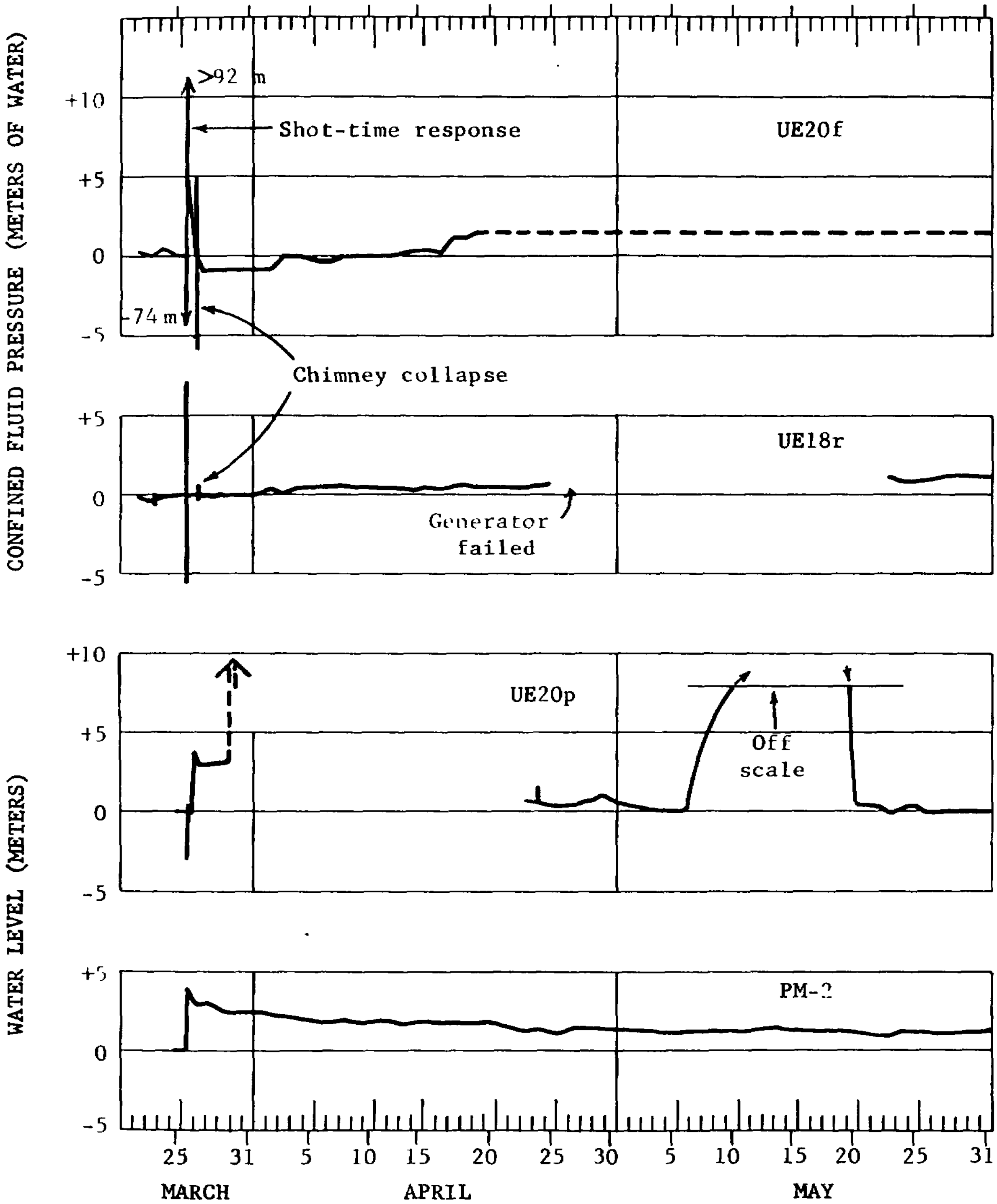


Figure 17.--Confined fluid pressures in holes UE20f and UE18r, and water levels in holes UE20p and PM-2 after the Handley event.

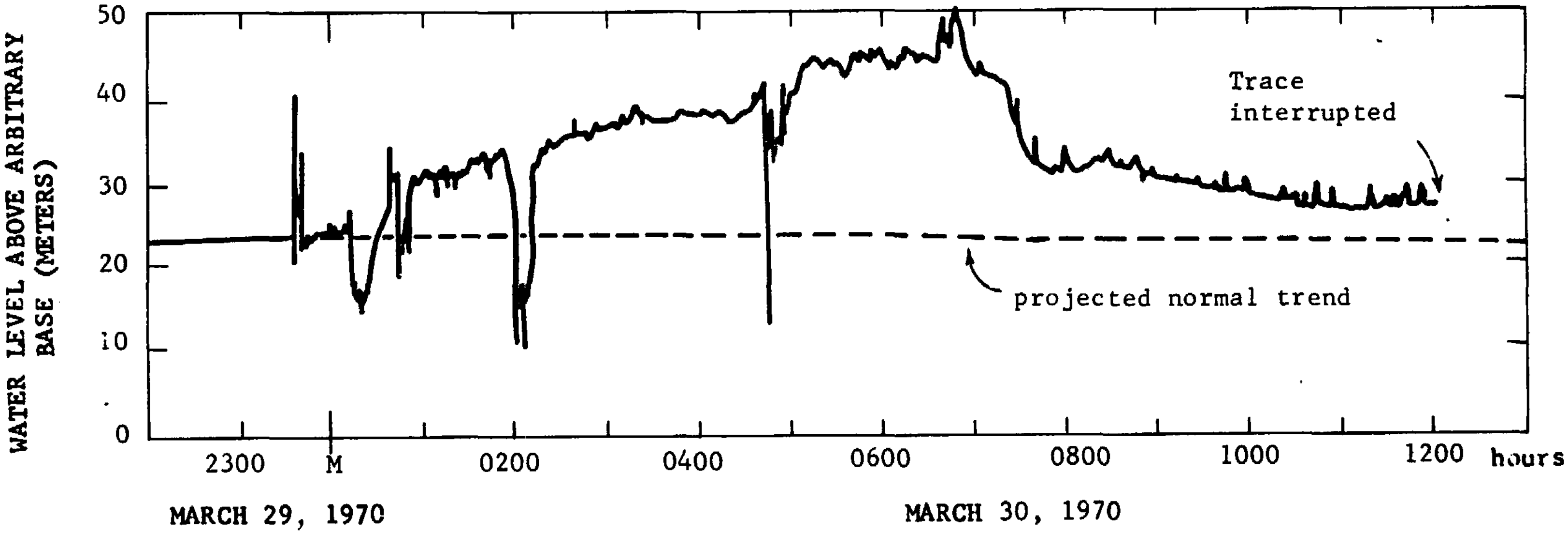


Figure 18.--Tracing of the UE20p water-level record of March 29-30, 1970.

Similar effects result from the lower yield explosions beneath Yucca Flat. The Bilby event (U3cn) in Area 3, having a reported yield of approximately 200 kt, caused the fluid level to rise about 250 feet (76 m) in an observation well 2,000 feet (610 m) from the explosion site (fig. 19). It is not known whether these observed water levels represent increases of the water-table altitude or merely pressure increases that can dissipate only slowly in the impermeable tuffs. In either case, they indicate explosion-caused hydraulic mounds that may be responsible for the surprisingly high water levels found in some exploratory and emplacement holes drilled near earlier explosion sites.

STOP NO. 7--NUCLEAR EXPLOSION CAVITIES--COLLAPSE, SURFACE SUBSIDENCE AND CRATERING

The mechanism of collapse of nuclear explosion cavities has been investigated by the USGS for its value in containment, with the hope of eventually determining those geologic environments most susceptible to early collapse or most adaptable to the incitation of collapse. The Survey has confined its investigations mainly to subsurface collapse and surface subsidence that result from explosions in the alluvium of Yucca Flat. The Survey's interest and needs will be satisfied only by the eventual understanding of the influence of various rock media, other than alluvium, on the collapse mechanism.

Collapse has long been recognized as highly beneficial in underground testing because it was found, as early as July 1962, that any accidental violent eruption (dynamic venting) of the gas, which is formed by an underground explosion, was cut off by collapse. Although such dynamic eruptions are infrequent and occur for a variety of reasons that are apparently unrelated to collapse, much effort is devoted in pretest planning to the expected time of collapse and to what can be done to assure that collapse occurs after as brief a time as practicable.

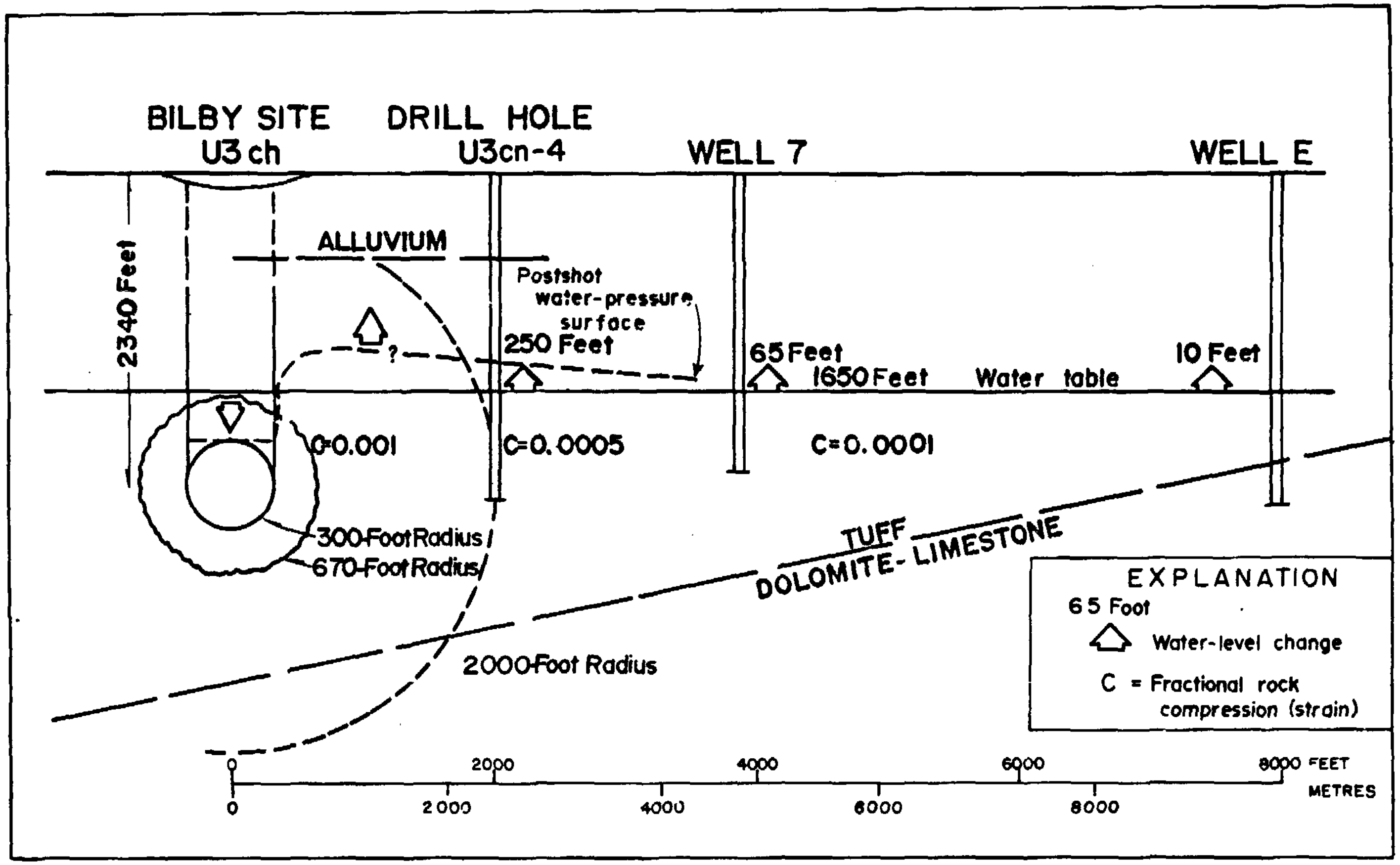


Figure 19.--Pore-pressure response to the Bilby event, September 1963.

The topographic depressions formed as a result of surface subsidence--termed "sinks"--are as much as 200 feet (61 m) deep and 800 feet (244 m) in radius; their forms are commonly variations of inverted cones or sectors of spheres. The central area of each sink is the top of a plug whose size, shape, and vertical drop all strongly influence the size and profile of the sink. A block that surrounds the central plug in the vast majority of sinks is an inward slide mass of slightly disoriented but relatively undisturbed alluvium. The main structural features within the slide mass are subsidiary spoon-shaped cracks and slide surfaces along which individual blocks have adjusted within the slide mass. The cracks or slide surfaces are assumed to flatten with depth within the slide and to join a major surface of failure at the base of the main slide mass. Where the spoon-shaped surfaces intersect the top surface of the slide, they dip steeply to vertically and, in plan, they make a pattern of curving intersecting cracks. Surrounding the slide mass are blocks that are extensively fractured and, in part, downdropped; these blocks form zones that are analogous to structural deformation at the heads of natural landslides.

The depth of burial in alluvium of the explosion cavity, relative to its size, affects the relief and morphology of the sink; for a collapse not extending to the surface, the depth of burial affects the height of the chimney and, to an extent, the likelihood that later surface subsidence will occur.

A working model of collapse includes: (a) preservation of the explosion cavity until main collapse occurs; (b) a two-phase collapse taking place in several seconds to tens of seconds, culminating in (c) surface subsidence if the cavity is sufficiently close to the surface. The first phase of collapse, in alluvium at least, consumes 75-90 percent of the collapse period; collapse propagates upward at rates of 50-80 f/s (feet per second) (15-24 m/s). The second phase shows faster rates of upward propagation and a lesser degree of particulation of the collapse material, and it ends with the drop of a central mass of alluvial material that initiates formation of the sink.

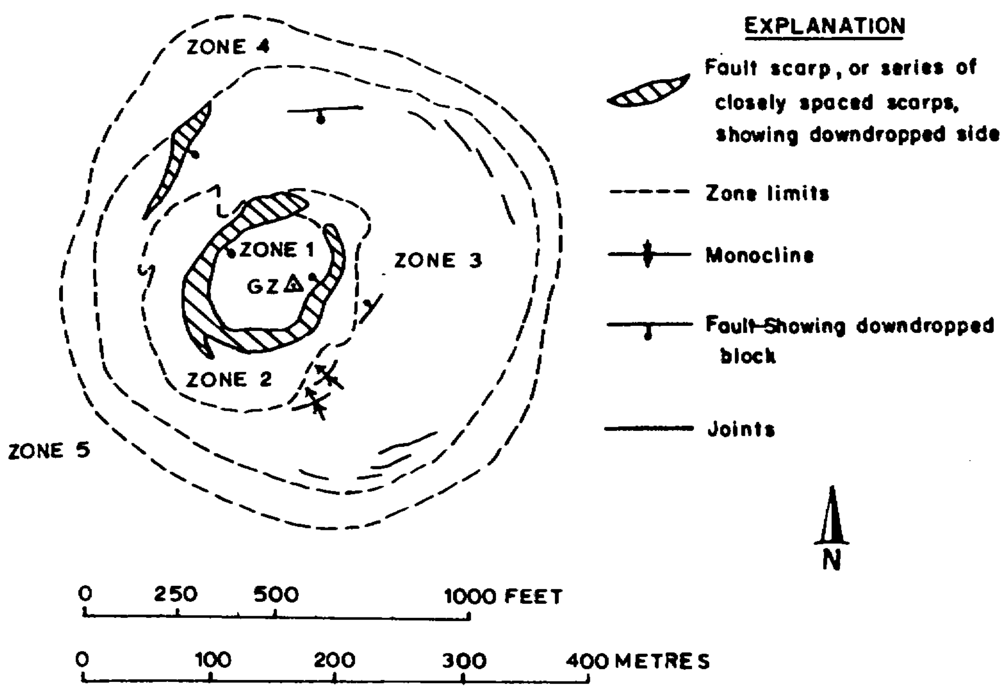
STARWORT SINK

The sink to be visited on this field trip is Starwort, the site of a detonation in the spring of 1973. The explosion was of low to intermediate yield and was buried at a depth of 1,850 feet (564 m) in volcanic tuff overlain by 1,310 feet (399 m) of alluvium. The emplacement of the device was generally conventional for that period--a cased large-diameter drill hole stemmed with pea gravel and sand and cement plugs at intervals up the hole above the device.

The U2bs (Starwort) sink formed at 3 hours, 48 minutes, 57 seconds after detonation. It measures 1,190 and 1,140 feet (363 and 347 m) (maximum and minimum diameter) and an estimated 125 feet (38 m) deep. The center of the sink is less than 50 feet (15 m) west of SGZ (surface ground zero). Zones 104 are well displayed (fig. 20) but, as can be seen, they are not developed concentrically with respect to SGZ.

CLOSE-IN HYDROLOGIC STUDIES--STARWORT EVENT

Predictions of the rate and direction of radionuclide movement away from event sites through ground-water systems are limited by the degree of understanding of the systems. Part of this understanding involves the physical, hydraulic, and radiochemical characteristics of the point of origin of the radionuclides--the explosion cavity, chimney, and induced fractures. A program of measurement and observation has been initiated at the site of the Starwort event. A postevent drill hole penetrates the explosion cavity (fig. 21), and completion of the hole is designed to allow the necessary measurements. By recording changes in temperature,



Definitions of structural zones:

Zone 1.--Comprises central part of sink where major subsidence occurred. Characterized by radial fractures and pressure ridges and, in deeper sinks, by landslides. GZ, ground zero.

Zone 2.--Inward-dipping fault blocks outlined by intersecting concentric outward-dipping faults and fractures.

Zone 3.--Subsided slightly rotated or unrotated blocks outlined by steeply dipping intersecting concentric fractures; grabens are common. Inner edge of zone is generally lower than outer edge.

Zone 4.--Numerous concentric fractures; no obvious subsidence, but precise preshot and postshot contouring shows frequent broad depressions overlapping into Zone 5.

Zone 5.--Original terrain without obvious deformation related to subsidence. Commonly fractured by explosion-induced movement.

Figure 20.--Sink structure (Starwort event), Yucca Flat.

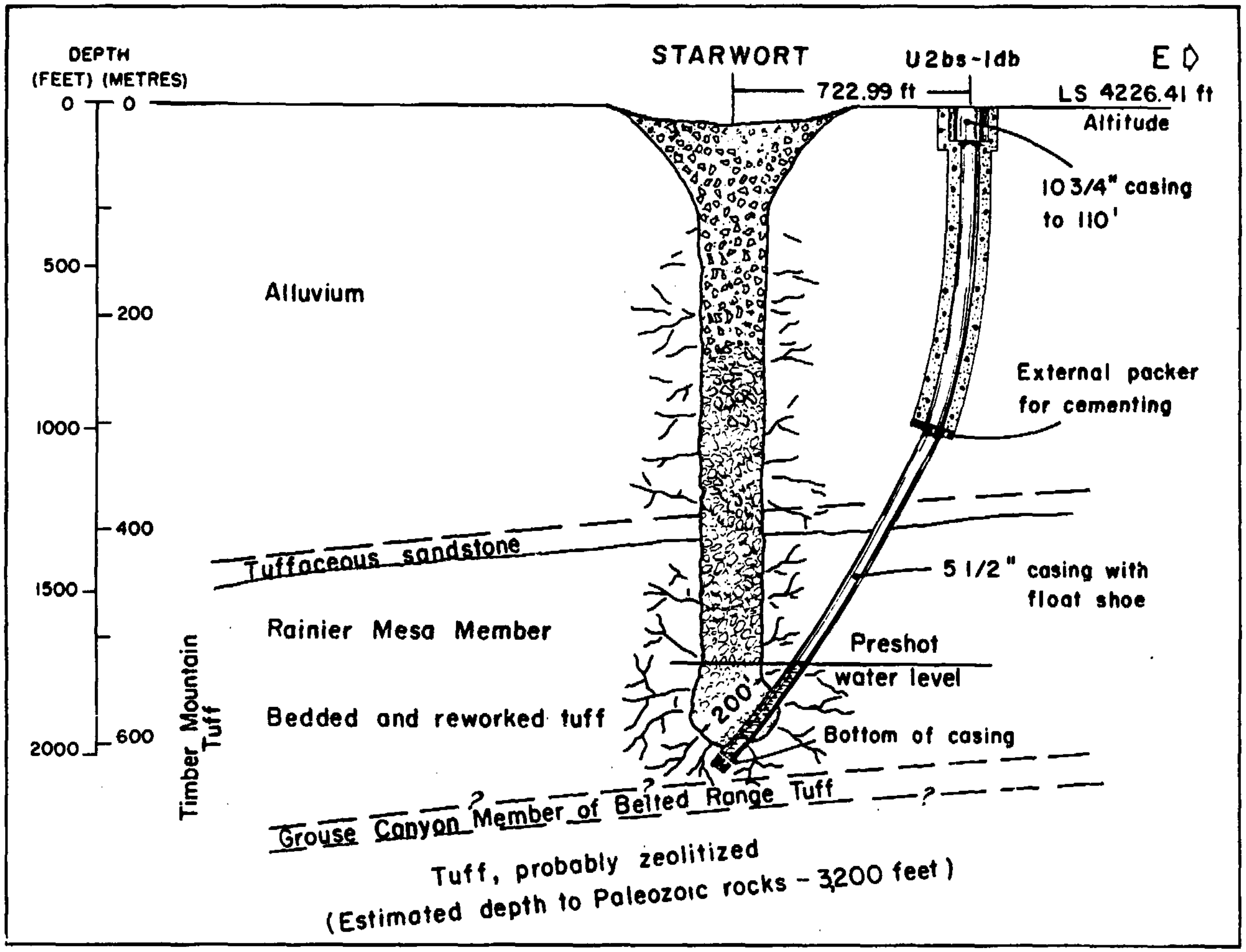


Figure 21.--Diagrammatic cross section through Starwort chimney and reentry hole.

pressure, and specific conductance of the borehole fluids and by sampling the fluids for radiochemical analysis, the program will (1) test a mathematical model for predicting chimney infill rates, (2) develop understanding of hydraulic phenomena occurring at the high temperatures anticipated, and (3) determine the changes in chemistry and radiochemistry of water entering the borehole through casing perforations as functions of time, temperature, and stage of chimney filling.

Later, at some time when the cavity and chimney have filled sufficiently with water, a pumping test will be made which will determine the hydraulic characteristics of the rubble-filled cavity.

STOP NO. 8--SEDAN CRATER

Cratering experiments, both high explosive and nuclear, were conducted principally during the period 1960-70. Several experiments of both types were conducted in alluvium and in bedrock in Frenchman Flat, Yucca Flat, and Pahute Mesa. The largest of these was the Sedan experiment in Yucca Flat.

The Sedan crater was formed on July 6, 1962, by a thermonuclear explosion (70 percent fusion, 30 percent fission) having a yield equivalent to 100 kt of TNT at a depth of 635 feet (194 m). The maximum depth of the crater was 320 feet (98 m) and the maximum diameter was 1,280 feet (390 m). The height of the lip ranges from 20 to 100 feet (6 to 30 m) above preshot levels. Ejecta were found as far as 5,800 feet (1,768 m) from ground zero.

Overturning of the alluvium strata in the lower part of the lip is similar to that at the Teapot-Ess nuclear crater, located about half a mile south of here, as described by Shoemaker (1960).

For the aid of the reader, geologic maps that include parts of the Nevada Test Site are outlined on figure 22 and arranged alphabetically in table 4.

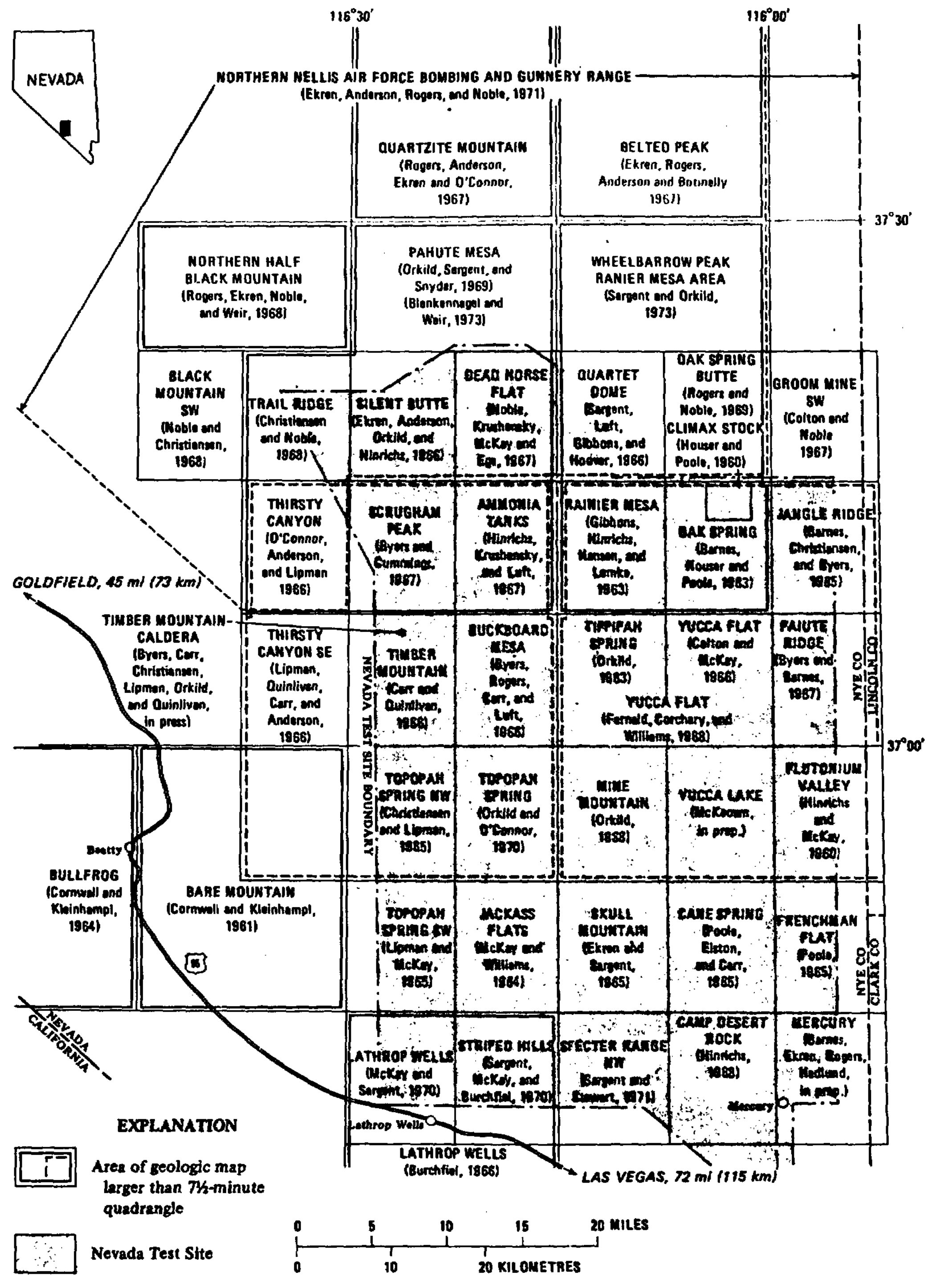


Figure 22.--Geologic maps of Nevada Test Site region published or in preparation by the U.S. Geological Survey (number designations shown in table 4).

(p. 55a follows)

Table 4.--Geologic Quadrangle (GQ-) and Miscellaneous Investigations (I-) maps and Professional Papers of Nevada Test Site and vicinity for sale by U.S. Geological Survey or Government Printing Office

[Order GQ- and I- maps from U.S. Geological Survey, Map Sales, Bldg. 41, Denver Federal Center, Denver, Colorado, 80225; discount, 30 percent on orders of $300.00 or more; order Professional Papers from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402]

Map or quadrangle name	Map designation	Author(s)
Ammonia Tanks	GQ-638	Hinrichs, E. N., Krushensky, R. D., and Luft, S. J.
Bare Mountain	GQ-157	Cornwall, H. R., and Kleinhampl, F. J.
Belted Peak	GQ-606	Ekren, E. B., Rogers, C. L., Anderson, R. E., and Botinelly, Theodore
Black Mountain SW	I-562	Noble, D. C., and Christiansen, R. L.
Buckboard Mesa	GQ-552	Byers, F. M., Jr., Rogers, C. L., Carr, W. J., and Luft, S. J.
Bullfrog	Prof. Paper 454-J	Cornwall, H. R., and Kleinhampl, F. J.
Camp Desert Rock	GQ-726	Hinrichs, E. N.
Cane Spring	GQ-455	Poole, F. G., Elston, D. P., and Carr, W. J.
Climax Stock	I-328	Houser, F. N., and Poole, F. G.
Dead Horse Flat	GQ-614	Noble, D. C., Krushensky, R. D., McKay, E. J., and Ege, J. R.
Frenchman Flat	GQ-456	Poole, F. G.
Groom Mine SW	GQ-719	Colton, R. B., and Noble, D. C.
Jackass Flats	GQ-368	McKay, E. J., and Williams, W. P.
Jangle Ridge	GQ-363	Barnes, Harley, Christiansen, R. L., and Byers, F. M., Jr.
Lathrop Wells, 7 1/2-min.	GQ-883	McKay, E. J., and Sargent, K. A.

(p. 56 follows)

Table 4.--Geologic Quadrangle (GQ-) and Miscellaneous Investigations (I-) maps and Professional Papers of Nevada Test Site and vicinity for sale by U.S. Geological Survey or Government Printing Office--Continued

Map or quadrangle name	Map designation	Author(s)
Lathrop Wells, 15-min.	I-474	Burchfiel, B. C.
Mercury	I- (in prep.)	Barnes, Harley, Ekren, E. B., Rogers, C. L., and Hedlund, D. C.
Mine Mountain	GQ-746	Orkild, P. P.
Northern Half Black Mountain	I-545	Rogers, C. L., Ekren, E. B., Noble, D. C., and Weir, J. E.
Northern Nellis Bombing and Gunnery Range	Prof. Paper 651	Ekren, E. B., Anderson, R. E., Rogers, C. L., and Noble, D. C.
Oak Spring	GQ-214	Barnes, Harley, Houser, F. N., and Poole, F. G.
Oak Spring Butte	GQ-822	Rogers, C. L., and Noble, D. C.
Pahute Mesa	I-567	Orkild, P. P., Sargent, K. A., and Snyder, R. P.
Pahute Mesa (hydrology)	Prof. Paper 712-B	Blankennagel, R. K., and Weir, J. E.
Paiute Ridge	GQ-577	Byers, F. M., Jr., and Barnes, Harley
Plutonium Valley	GQ-384	Hinrichs, E. N., and McKay, E. J.
Quartet Dome	GQ-496	Sargent, K. A., Luft, S. J., Gibbons, A. B., and Hoover, D. L.
Quartzite Mountain	GQ-672	Rogers, C. L., Anderson, R. E., Ekren, E. B., and O'Connor, J. T.
Rainier Mesa	GQ-215	Gibbons, A. B., Hinrichs, E. N., Hansen, W. R., and Lemke, R. W.
Scrugham Peak	GQ-695	Byers, F. M., Jr., and Cummings, David

Table 4.--Geologic Quadrangle (GQ-) and Miscellaneous Investigations (I-) maps and Professional Papers of Nevada Test Site and vicinity for sale by U.S. Geological Survey or Government Printing Office--Continued

Map or quadrangle name	Map designation	Author(s)
Silent Butte	GQ-493	Ekren, E. B., Anderson, R. E., Orkild, P. P., and Hinrichs, E. N.
Skull Mountain	GQ-387	Ekren, E. B., and Sargent, K. A.
Specter Range	GQ-884	Sargent, K. A., and Stewart, J. H.
Striped Hills	GQ-882	Sargent, K. A., McKay, E. J., and Burchfiel, B. C.
Thirsty Canyon	GQ-524	O'Connor, J. T., Anderson, R. E., and Lipman, P. W.
Thirsty Canyon SE	GQ-489	Lipman, P. W., Quinlivan, W. D., Carr, W. J., and Anderson, R. E.
Timber Mountain	GQ-503	Carr, W. J., and Quinlivan, W. D.
Timber Mountain caldera	I-891 (in prep.)	Byers, F. M., Jr., Carr, W. J., Christiansen, R. L., Lipman, P. W., Orkild, P. P., and Quinlivan, W. D.
Tippipah Spring	GQ-213	Orkild, P. P.
Topopah Spring	GQ-849	Orkild, P. P.
Topopah Spring NW	GQ-444	Christiansen, R. L., and Lipman, P. W.
Topopah Spring SW	GQ-439	Lipman, P. W., and McKay, E. J.
Trail Ridge	GQ-774	Christiansen, R. L., and Noble, D. C.
Wheelbarrow Peak-Rainier Mesa	I-754	Sargent, K. A., and Orkild, P. P.
Yucca Flat (1:24,000)	GQ-582	Colton, R. B., and McKay, E. J.
Yucca Flat (1:48,000)	I-550	Fernald, A. T., Corchary, G. S., and Williams, W. P.
Yucca Lake	GQ- (in prep.)	McKeown, F. A.

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