see pocket 4 for enclosure TRIP report

OAK RIDGE NATIONAL LABORATORY
OPERATED BY MARTIN MARIETTA ENERGY SYSTEMS, INC.

POST OFFICE BOX X
OAK RIDGE, TENNESSEE 37831

WM DOCKET CONTROL CENTER

'84 DEC 19 AM

December 14, 1984

WM-RES

WM Record File B-0287 ORNL
WM Project 10, 11, 16
Docket No.
PDR ✓
LPDR B, N, S

Distribution:
D Brooks

(Return to WM, 623-SS)

Dr. D. J. Brooks
Geotechnical Branch
Office of Nuclear Material
Safety and Safeguards
U.S. Nuclear Regulatory Commission
623-SS
Washington, D.C. 20555

Dear Dave:

Enclosed is a copy of Jim Blencoe's and Gary Jacobs's trip report (MR-287-1) to attend the Geological Society of America meeting in Reno, Nevada, on November 2-10, 1984.

Sincerely,

Susan

Susan K. Whatley, Manager
Repository Licensing Analysis
and Support
Chemical Technology Division

SKW:kk

Enclosure

cc: J. W. Bradbury, Geotechnical Branch
W. Dam, Geotechnical Branch
W. R. Kelly, Geotechnical Branch
L. Kovach, Geotechnical Branch
R. J. Starmer, Geotechnical Branch
J. G. Blencoe
N. H. Cutshall
L. M. Ferris
G. K. Jacobs
A. D. Kelmers
A. P. Malinauskas
SKW File

1720

See folder for letter to Brooks from Whatley 12/14/84
MR-287-1
12/14/84

TRIP REPORT OF GEOLOGICAL SOCIEITY OF AMERICA MEETING AT RENO, NEVADA

AUTHORS: J. G. Blencoe and G. K. Jacobs

LOCATIONS: Nevada Test Site (pre- and post-meeting field trips) and Reno, Nevada (GSA Annual Meeting)

DATES: Pre-meeting field trip--November 2-4, 1984; GSA Annual Meeting--November 5-8, 1984; Post-meeting field trip--November 8-10, 1984

PURPOSE: Participate in field trips to the Nevada Test Site, and attend the Annual Meeting of the Geological Society of America.

PROJECT TITLE: Technical Assistance in Geochemistry.

PROJECT MANAGER: S. K. Whatley.

ACTIVITY NUMBER: ORNL #41 37 54 92 4 (189 #B0287)/NRC #50 19 03 01.

SUMMARY

This report describes the activities and experiences of J. G. Blencoe and G. K. Jacobs during: (1) pre- and post-meeting field trips to the Nevada Test Site (NTS), and (2) the annual meeting of the Geological Society of America (GSA). The pre-meeting field trip, attended by J. G. Blencoe, was conducted to examine the geology of the NTS. The post-meeting field trip, attended by G. K. Jacobs, was undertaken to review the regional flow systems, groundwater recharge, and unsaturated flow within the NTS and adjacent areas. The GSA Annual Meeting was attended by both J. G. Blencoe and G. K. Jacobs.

GENERAL OBSERVATIONS AND COMMENTS ON THE GSA MEETING AT RENO

The 1984 GSA Annual Meeting was held in the MGM Grand Hotel in Reno, Nevada, on November 5-8. Approximately 6,000 geoscientists were present at the meeting, making it the most well-attended GSA annual meeting ever.

Symposium on the Geology, Hydrology, and Geochemistry of the NTS 2:00 p.m., November 5, 1984)

In addition to the usual technical sessions on geoscientific subjects (petrology, paleontology, geophysics, etc.), this year's GSA Annual Meeting included a half-day symposium on the geology, hydrology, and geochemistry of the NTS. The speakers who delivered presentations at this symposium, and the titles of their papers, are:

1. Thomas R. Clark: The Role of Earth Science at the Nevada Test Site--The Manager's Viewpoint.

2. H. Lawrence McKague, Paul P. Orkild: Geologic Framework of Nevada Test Site.

3. Carol J. Boughton, Roger L. Jacobson, John W. Hess: Regional Groundwater Characteristics Determined From Geochemistry and Environmental Isotopes at the Nevada Test Site.

4. W. J. Carr: Timing and Style of Tectonism and Localization of Volcanism in the Walker Lane Belt of Southwestern Nevada.

5. Robert B. Scott: Internal Deformation of Blocks Bounded by Basin-and-Range-Style Faults.

6. Barney J. Szabo: Uranium-Series Dating of Fault-Related Fracture- and Cavity-Filling Calcite and Opal in Drill Cores From Yucca Mountain, Southern Nevada.

7. Christopher C. Barton: Tectonic Significance of Fractures in Welded Tuff, Yucca Mountain, Southwest Nevada.

8. Richard K. Waddell: Solute-Transport Characteristics of Fractured Tuffs at Yucca Mountain, Nevada Test Site--A Preliminary Assessment.

9. Norman R. Burkhard: Applications of Geophysical Exploration Techniques to Structural Interpretations at the Nevada Test Site.

10. J. N. Rosholt, C. A. Bush, W. J. Carr: Uranium-Trend Dating and its Application to Quaternary Deposits in the Nevada Test Site Region.

11. J. L. Wagoner, H. L. McKauge: The Alluvial Valley Fill, Yucca Flat, Nevada.

12. Clinton M. Case, Mark Kautsky, Peter M. Kearl, Diane M. Nork, Thomas F. Panian, Sarah L. Raker: Unsaturated Flow Through the Alluvium at the Nevada Test Site.

13. Stephen W. Wheatcraft, Thomas J. Burbey: Numerical Modeling of the Tritium Breakthrough at the Cambric Site, Nevada Test Site.

14. Richard H. French: Assessment of Flood Risk to Facilities Sited on Alluvial Fans at the Nevada Test Site.

15. E. M. Romney: Restoration of Vegetation in Areas Disturbed by Nuclear Testing at the Nevada Test Site.

Our principal observation concerning these papers is that the speakers did not focus on information obtained recently, and most of the discussions were directed toward the hydrology and geology of the entire NTS (i.e., very little was said about the "local" hydrology, geology, and geochemistry of Yucca Mountain). Furthermore, many of the presentations were poorly delivered, and sometimes accompanying slides were difficult to read.

Miscellaneous Papers on Topics Related to Disposal of High-Level Radioactive Waste

Several technical sessions held during the Annual Meeting included presentations that dealt with the geochemistry of brines at the various candidate salt sites (however, most of the discussions focused on the Palo Duro Basin site). From the talks dealing with the Palo Duro Basin site, we learned that the deep water-bearing Wolfcamp Formation is being studied extensively by the Texas Bureau of Economic Geology to determine: (1) the source(s) and age(s) of the fluids, and (2) the significance of brine chemistry for conceptual models of groundwater flow.

Several technical sessions devoted to geochemical topics included interesting presentations on rock/water interactions. For example, a researcher from Stanford University described experimental work that he has performed on the solubility of UO_2 at high temperatures. His data suggest that calculated solubilities of UO_2 at 100-300°C obtained from the thermodynamic data that is currently available may be off by as much as 3-4 orders of magnitude! There were also several papers which described work currently being performed on the mechanisms of oxidation and reduction of aqueous species at or near the surfaces of minerals. Still another interesting paper presented evidence that some form of bacteria may have been found in fluid inclusions from a geothermal area (temperatures up to 200°C). This is the first observation of this sort and it may have implications for evaluations of the significance of bacterial processes in the mobilization and retention of radionuclides released from a repository. In the past, it has been considered that bacteria would not survive the thermal period; however, it seems evident now that the validity of this assumption should be reassessed.

Conclusions

As expected, this year's GSA Annual Meeting included the usual mix of excellent, good, mediocre, and terrible talks. However, in our opinion, the overall "value" of the meeting is not properly assessed by considering only the number of interesting talks that were delivered during the technical sessions. In addition to being able to attend technical sessions that dealt wholely, or in part, with waste-management subjects, the meeting provided us with an opportunity to verbally exchange information with colleagues from other national laboratories and from universities who share some of our interests and concerns regarding the geochemistry of high-level waste (HLW) disposal. Such exchanges enhance our professional development in three ways: (1) we gain knowledge directly from our peers in a scientific atmosphere that encourages expression of honest opinion; (2) by meeting and talking with our peers face-to-face, we establish a positive standing and credibility among scientists who are working on HLW disposal problems; and (3) we reestablish old contacts with peers, and make new contacts, which preserve or open up lines of communication which can be of great value at a later time (e.g., when it is necessary to obtain new information quickly, and you are wondering who to contact to obtain this information). In view of these beneficial aspects of attending this year's meeting, we hope that the NRC will allow up to attend future GSA Annual Meetings.

COMMENTS ON THE PRE- AND POST-MEETING FIELD TRIPS TO THE NEVADA TEST SITE

Field Trip on the Geology of the Nevada Test Site (J. G. Blencoe)

a. Comments concerning events and observations on the first day of the field trip (November 3, 1984)

The first day of the field trip was spent traveling from Las Vegas to Mercury (NTS) and observing the geology along the way. It was emphasized that, while the rocks around Las Vegas are Precambrian or Paleozoic in age, and contain many sedimentary lithologies, the rocks on--and adjacent to--the NTS are predominantly Cenozoic (mainly Miocene) and Recent volcanic rocks. Due to the significant distance that we had to travel, we only made a few stops to perform some "roadside geology;" the rest of the time was spent observing distant rock formations through the windows of the bus. There were no discussions of a geochemical nature at all during the day, which was disappointing. I suspected that geochemistry would not be emphasized in verbal discussions presented by our field-trip guides, mainly because the field trip was advertised as a geology field trip, but I was a little surprised that no attempts were made to present information that would have been of great interest to geochemists. (For example, it would have been very interesting to learn more about the patterns of alteration of tuffaceous rocks at the NTS.) However, the day was "saved" (from the point of view of this geochemist) by two events: a brief visit to Yucca Mountain in the early afternoon, and a tour of the USGS Core Library at Mercury at the end of the day.

The visit to Yucca Mountain was rewarding because, after seeing it, I now have a good mental image of the topographic and geologic environment of the candidate-repository site at Yucca Mountain. During the brief lunch-hour stop at the summit of the mountain (Yucca Mountain is actually a broad ridge), there were detailed discussions of the regional geology and hydrology of the area, but essentially no discussion of the geochemistry of the rocks beneath the mountain. Nevertheless, the lectures delivered by the field-trip leaders were interesting, especially the presentation given by Rick Waddell of the USGS. From his talk I conclude that the hydrology of the Yucca Mountain region is still poorly understood, the principal unknowns being: (1) the rate of groundwater recharge at Yucca Mountain, and (2) the rates and volumes of fracture flow vis-a-vis matrix flow of groundwater at the site.

The visit to the USGS Core Library at Mercury was the last stop of the day. This core library, officially designated "The Geologic Data Center and Core Library" at Mercury, 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 serves as: (1) a field headquarters for USGS geologists, hydrologists, and geophysicists, and (2) a work area for earth scientists employed in support of weapons testing and DOE waste-management projects. The facility maintains reference files of reports, maps, aerial photographs, and downhole video tapes and geophysical logs for selected drill holes at the NTS and other test areas. Water samples are analyzed both chemically and radiologically in a hydrologic-chemical laboratory adjacent to the Core Library.

Continuous core, sidewall samples, and rock cuttings stored at the Core Library have been used to resolve geologic problems encountered by personnel concerned with nuclear-test containment and HLW disposal. For example: (1) primary minerals and whole rocks are analyzed to help correlate volcanic units found at the Test Site, and (2) secondary (diagenetic) minerals have been studied intensively to gauge their ability to inhibit migration of radionuclides. Regarding (1), LANL geochemists are analyzing phenocryst minerals and whole rocks to model the origin and evolution of the late-Tertiary volcanic sequence at the NTS. Recent work has allowed accurate correlation of individual petrologic units as well as entire petrologic suites. The spatial distribution patterns of correlative petrographic units point to the Timber Mountain - Oasis Valley magmatic system as the primary source of Miocene volcanic rocks at the NTS. This observation, along with supporting geochemical data, indicates that Miocene volcanic rocks at the NTS are the effusive product of a single, large, evolving rhyolitic-magma body that was located beneath the present expression of the Timber Mountain Caldera.

b. Comments concerning events and observations on the second day of the field trip (November 4, 1984)

Like the first day of the field trip, activities on this day consisted mainly of "geologic sight-seeing." The highlight of the day was a visit to the SEDAN crater, a circular pit--approximately 390 m in diameter and 98 m deep--which was formed in tuffaceous alluvium just to the east of Rainier Mesa as a result of the detonation of a 100 kt atomic device on July 6, 1962. During the stop at this crater, there was much discussion of "containment geology" (geologic studies in support of underground testing of nuclear devices) and nuclear-excavation scaling laws (the empirical relationships between the kilotonnage of an atomic device, depth of detonation, and the size of the resulting crater produced by the explosion of the device).

The only activity of the day which possessed a geochemical "flavor" was a visit to the Radionuclide Migration (RNM) project site on Frenchman Flat. The RNM project was initiated in 1974 to study the rates of underground migration of radionuclides from explosion-modified zones at the site of the "Cambric event." The Cambric event, which refers to the detonation of an atomic device beneath Frenchman Flat in 1965, was chosen for study because, among other amenable conditions: (1) sufficient tritium was present to provide an easily measureable tracer for water from the cavity region; (2) the post-shot debris and groundwater in the cavity and overlying chimney contained quantities of plutonium, uranium, and fission products that were sufficient for measurement and comparison; (3) the small nuclear yield from the Cambric event was expected to have little effect on the local hydrology; and (4) it was judged that alluvium is a good medium for radionuclide-migration studies because it is more permeable than tuff and does not contain large fractures through which groundwater might selectively flow.

Beginning in October, 1975, water was pumped from a satellite well located 91 m from the Cambric cavity; this produced an artificial gradient that was sufficient to draw water from the Cambric cavity, thereby providing an opportunity to study radionuclide migration under field conditions. The satellite well was pumped at the rate of ~600 gal/m. Every week samples were taken and analyzed for radionuclides. The first radionuclide detected was ^{36}Cl. Later (in the summer of 1978), tritium was detected, and by late summer, 1980, the concentration of this radionuclide reached a peak of 7000 pCi/mL. By September 30, 1982, over 42% of the tritium from the Cambric event had been removed by the satellite well.

Field Trip on the Hydrogeology of the Nevada Test Site and Amargosa Desert (G. K. Jacobs)

This field trip was excellent. We observed and discussed many aspects of the flow regimes pertinent to the area (ie., alluvium, tuff, and Palezoic carbonates). There is apparently still significant controversy concerning not only the location of recharge and discharge areas, but also the potential impact of groundwater flow on the containment and isolation of radionuclides resulting from the testing of nuclear devices and the proposed repository at Yucca Mountain.

Because a nuclear device was scheduled to be tested at the NTS on Friday, November 9, the field trip was run in reverse order from that described in the field trip guide. We were supposed to be able to get onto the NTS on Saturday in order to observe and discuss the hydrology of Yucca Mountain and other aspects of the NTS. As it turned out, the device was tested on the morning of Saturday, November 10. Therefore, our first stop that day was Yucca Mountain and the rest of the NTS portion of the field trip followed.

a. Comments concerning events and observations on the first day of the field trip (November 9, 1984)

The first day was spent traveling from Las Vegas to Beatty through the Amargosa Desert to observe and discuss hydrologic characteristics of the area. The Amargosa Desert is a possible discharge area for groundwaters which originate within the NTS. Groundwater discharge occurs as small springs emanating from Palezoic carbonate units. We observed a population of pupfish — "minnow-like" fish which live in the springs of the Amargosa Desert. These pupfish are significant because a large irrigation project in the desert was discontinued when it was shown that overpumping of the aquifer system was lowering the level of water in the springs to a point below which the pupfish could no longer reproduce — thus endangering their existence.

During the day, useful discussions concerning the regional geology and hydrology occurred with the participants and leaders of the field trip. These discussions were particularly interesting because the field trip leaders were with the Desert Research Institute (DRI) and are currently involved in evaluating the hydrochemical work which is being carried out by the USGS and LANL. Apparently, DRI has access to water samples and other hydrologic data being collected by the USGS and LANL.

The last stop of the day was at the U.S. Ecology waste disposal area, just outside of Beatty, NV. This facility accepts low-level radioactive waste as well as toxic chemical waste. Only solidified waste are currently disposed of at the facility. We observed and discussed the disposal practices including the segregation of wastes and the hydrology of the unsaturated zone in which the facility is located.

b. Comments concerning events and observations on the second day of the field trip (November 10, 1984)

The first stop was at Yucca Mountain to observe a pump test which was being conducted. We discussed the general geology and hydrology of the Yucca Mountain area, however, few details were covered. As J. G. Blencoe discussed earlier, being able to visualize the geologic and hydrologic setting of Yucca Mountain will be valuable in future review efforts concerning the NNWSI Project.

The next major stop was at a low-level waste (LLW) site on the NTS. This site has been instrumented to investigate the hydrology of the unsaturated zone as related to the disposal of LLW. DRI is involved in many studies of unsaturated zone hydrology. Though much uncertainty remains in their understanding of the hydrology of the unsaturated zone, the residence time of water in the unsaturated alluvium is thought to be on the order of months. Therefore, it is possible that the conceptual model of NNWSI for the rapid transport of water through the unsaturated zone — thus little time for reaction with repository materials — may be realistic, although the repository will be constructed in rock, whereas most studies to date by DRI have addressed the alluvium.

Also included in this field trip were stops to the SEDAN crater and the Radionuclide Migration (RNM) site on Frenchman Flat. These areas were discussed by J. G. Blencoe earlier and will not be repeated here.

NEVADA TEST SITE FIELD TRIP GUIDEBOOK 1984
(FIELD TRIP 10)

Leaders:
HOLLY D. ANDER, Los Alamos National Laboratory
F. M. BYERS, JR., Los Alamos National Laboratory
PAUL P. ORKILD, U.S. Geological Survey

With contributions from:
HARLEY BARNES (deceased), W. J. CARR, WILLIAM W DUDLEY, EVAN C. JENKINS, F. G. POOLE, RALPH R. SHROBA, ROBERT B. SCOTT, and MARTHA G. VAN WERKEN, U.S. Geological Survey

DAVID E. BROXTON, BRUCE M. CROWE, DONATHON J. KRIER, SCHON S. LEVY, WARD L. HAWKINS, DAVID T. VANIMAN, and RICHARD G. WARREN, Los Alamos National Laboratory.

FOREWORD

The Nevada Test Site (NTS) was established on December 18, 1950, to provide an area for continental testing of nuclear devices. In January of 1951 testing began with an airdrop into Frenchman Flat in conjunction with Operation Ranger. In addition to airdrops, above ground testing included surface detonations, tower shots, and balloon suspensions. Underground testing began in 1957 and, since 1963, all events have been buried in large diameter drill holes or tunnels. Geologists from the U. S. Geological Survey mapped much of the NTS region between 1960 and 1965. These maps have formed the basis for subsequent studies by geologic support groups from Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratory, 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 late Precambrian and Paleozoic rocks which were completely 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 late 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.

The editors would like to thank all of the co-authors who contributed to sections of this guidebook in their areas of expertise. Special thanks to Will Carr whose numerous additions and corrections to the roadlog were incorporated into the final draft. W. B. Myers and D. L. Nealey of the USGS reviewed the manuscript. Without the support of Jack House and Wes Myers of Los Alamos National Laboratory, this field trip would not have been possible.

Virginia Glanzman expedited the USGS peer review process and performed editorial duties. Barbara Hahn typed the manuscript and Mary Ann Olson and Luween Smith drafted many of the illustrations.

ROADLOG

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) indicates 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. B.P. (Longwell, 1974). The absolute amount of strike-slip movement

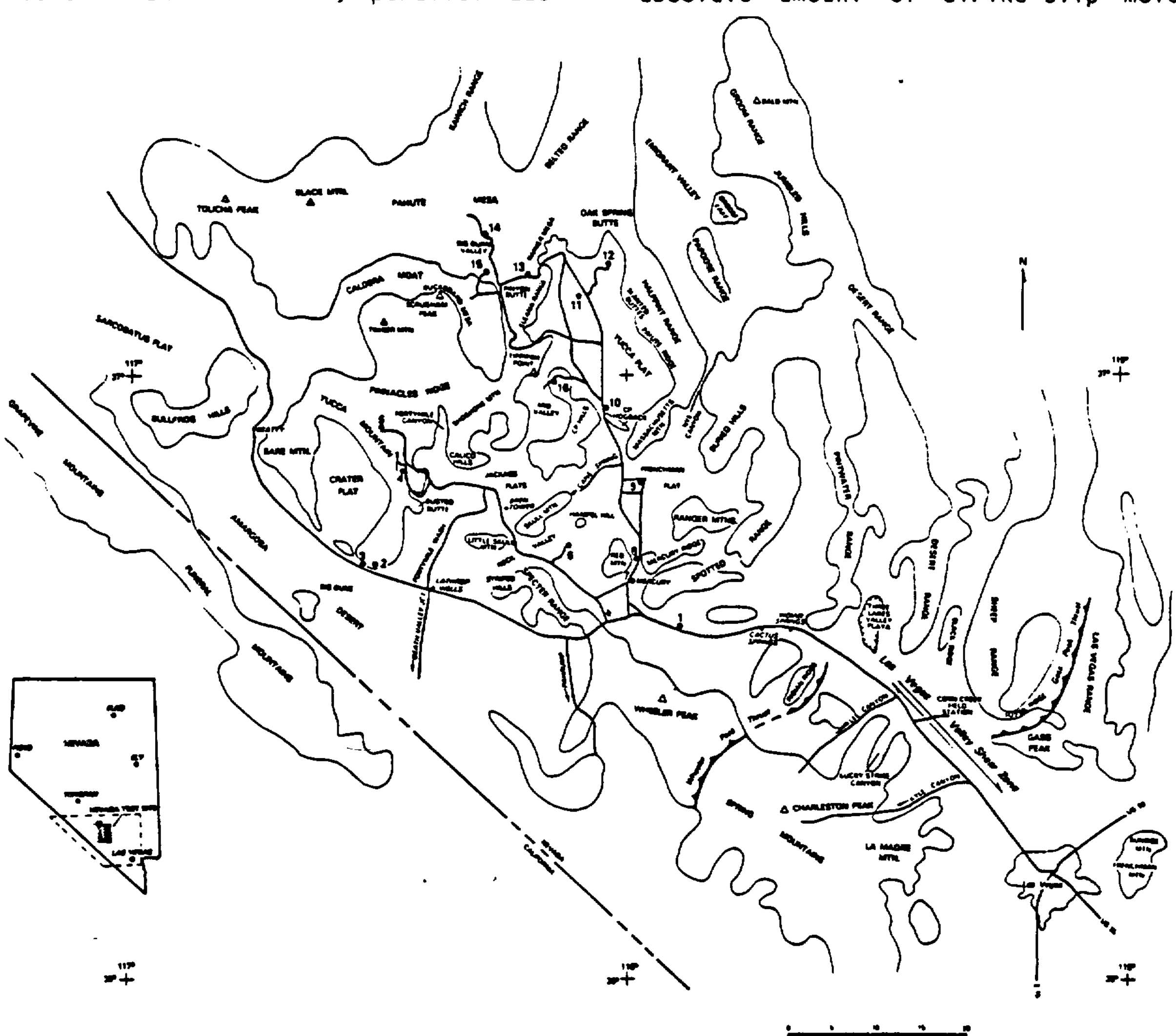

FIGURE 1: Southern Nevada region showing principal geographic features, probable offset of Wheeler Pass Thrust and coeval Gass Peak Thrust, and numbered stops on Nevada Test Site Field Trip.

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).

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 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 Navajo (Aztec) Sandstone of Triassic and Jurassic age, forms 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 Navajo 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 Dolomite 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 offer 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 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 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. 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 (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 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 at 11:00 north of Lucky Strike Canyon are the Pennsylvanian-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-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 11,918 ft. (3612 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 and Silurian-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 rock. 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. PALEOZOIC UNITS IN THE SPOTTED RANGE.
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 miogeosynclinal 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 1); Silurian and Lower Devonian dolomite; Lower and Middle Devonian dolomite and quartzite of the Nevada Formation, and Middle to Upper Devonian Devils Gate Limestone (includes some dolomite and quartzite). Uppermost Devonian and Lower to 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 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 consist 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 and Spotted Range can be correlated across Mercury Valley with little or no offset. No significant northwest-striking faulting is present in Plio-Pleistocene deposits of

TABLE 1

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 +		

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-Pliocene gravels contain at their base ash-fall tuff layers correlative with those at the base of the Paintbrush Tuff (Table 2), whose source is near the western edge of NTS, 56 km. to the northwest. Unconformably beneath the ash beds are steeply tilted early 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 crops out to right.

80.8 Bonanza King Formation exposures on left.

82.0 Rock Valley Wash.

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 yrs. ago.

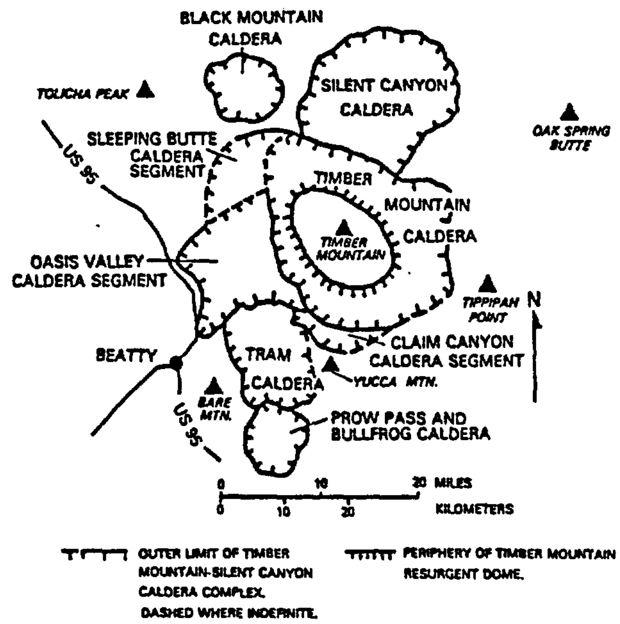

FIGURE 2: Nevada Test Site region showing caldera outlines, known and inferred.

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 2) repeated by northeast-striking faults.

TABLE 2

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

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 has 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., 1979) and R. F. Marvin (written commun., 1980).

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).

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.

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 which 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 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 yrs. (Fig. 5). The pyroclastic material locally became incorporated in late Pleistocene alluvium (Fig. 5) and a loessial silt deposit accumulated on the cinder cone and regionally on the Q2 alluvium prior to about 25,000 yrs. 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

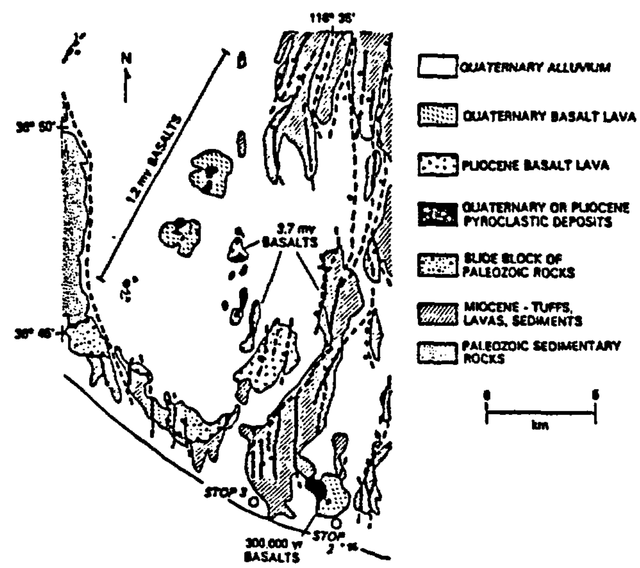

FIGURE 3: Southern Crater Flat area showing basalt centers and Stops 2 and 3 (modified from Crowe and Carr, 1980).

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.

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. old 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

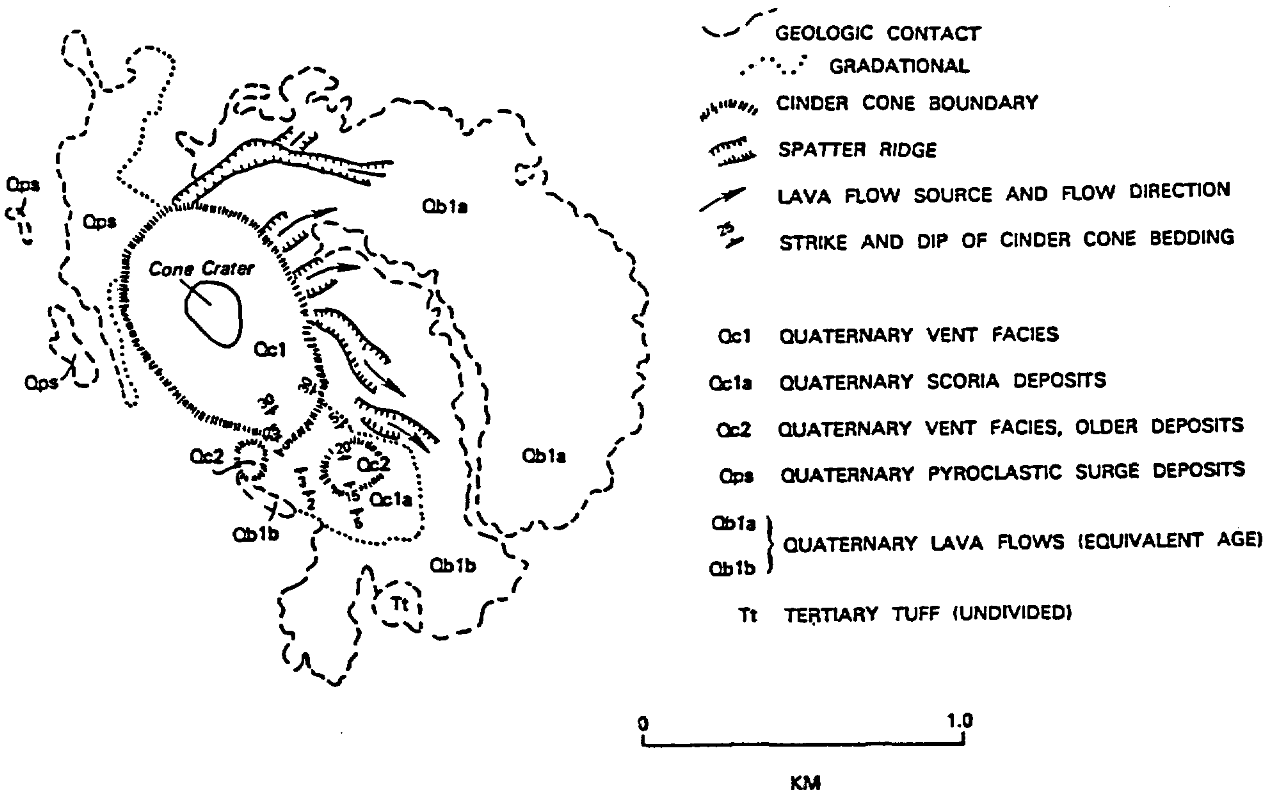

FIGURE 4: Geologic map of Lathrop Wells volcanic center (Stop 2).

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 yrs., 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-A dates are 300,000 yrs. for agglutinate in the summit crater, 290,000 yrs. for the lava, and 230,000 yrs. 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. CRATER FLAT TUFF.
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 mi. 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 2). The source areas for the Crater Flat Tuff

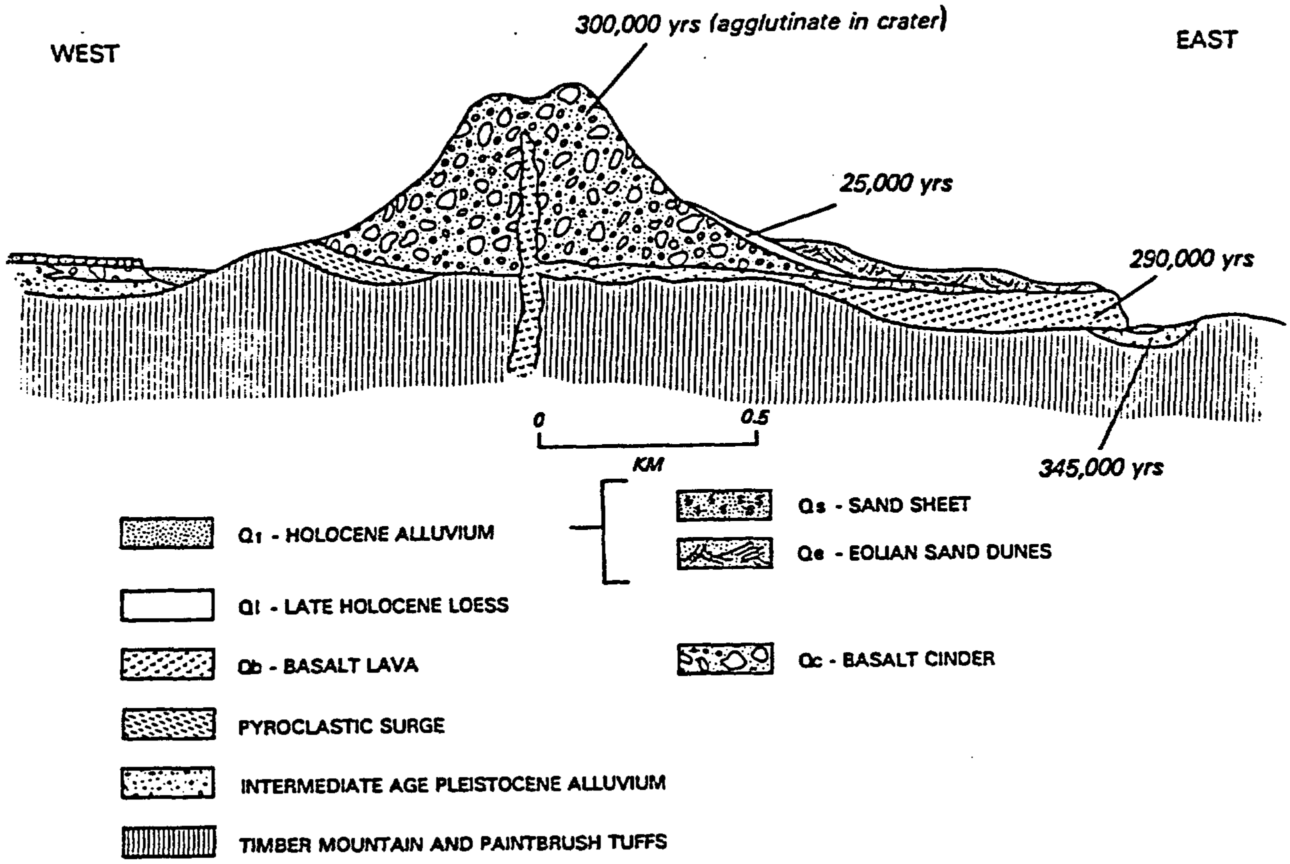

FIGURE 5: Sketch of geologic relations at Lathrop Wells volcanic center (Stop 2).

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 late 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 Area 20 Tuff 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 airfall 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

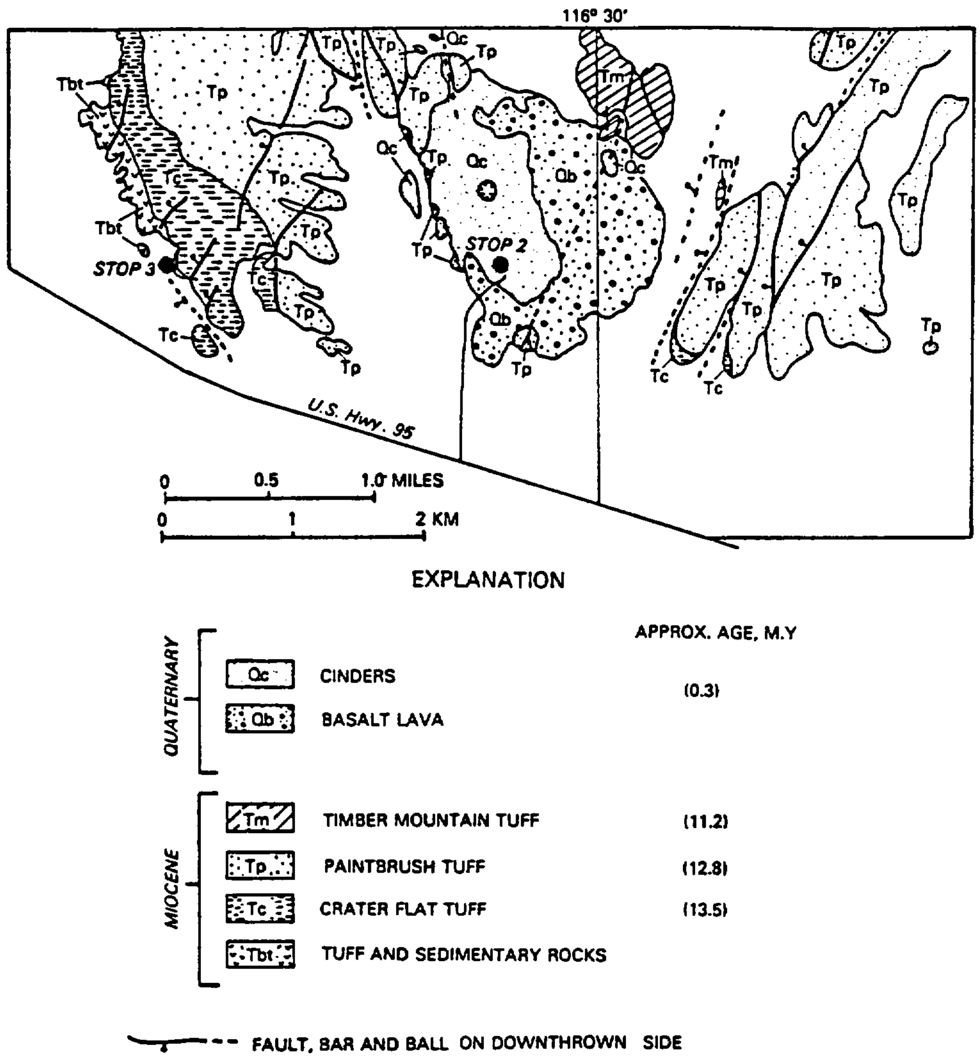

FIGURE 6: Generalized geologic map of type section area of Crater Flat Tuff (Stop 3).

welded, devitrified interior; and a non-welded, 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 Nevada Test Site (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. old; R. F. Marvin, 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. basalt (R. F. Marvin, written commun., 1980) of EMAD (Engine Maintenance and Disassembly).

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 NRDA facility, originally Nuclear Rocket Development Station, now called Nevada Research and Development Area.

119.0 On skyline at 12:00 Shoshone Mountain is capped by 8.9 m.y. old rhyolite lavas (R. F. Marvin, 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. old Rainier Mesa Member and the underlying 12.6 m.y. old Tiva Canyon Member (Marvin and others, 1970). Rainier Mesa Member laps across major faults with only minor displacement, if any, 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. YUCCA MOUNTAIN.
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.

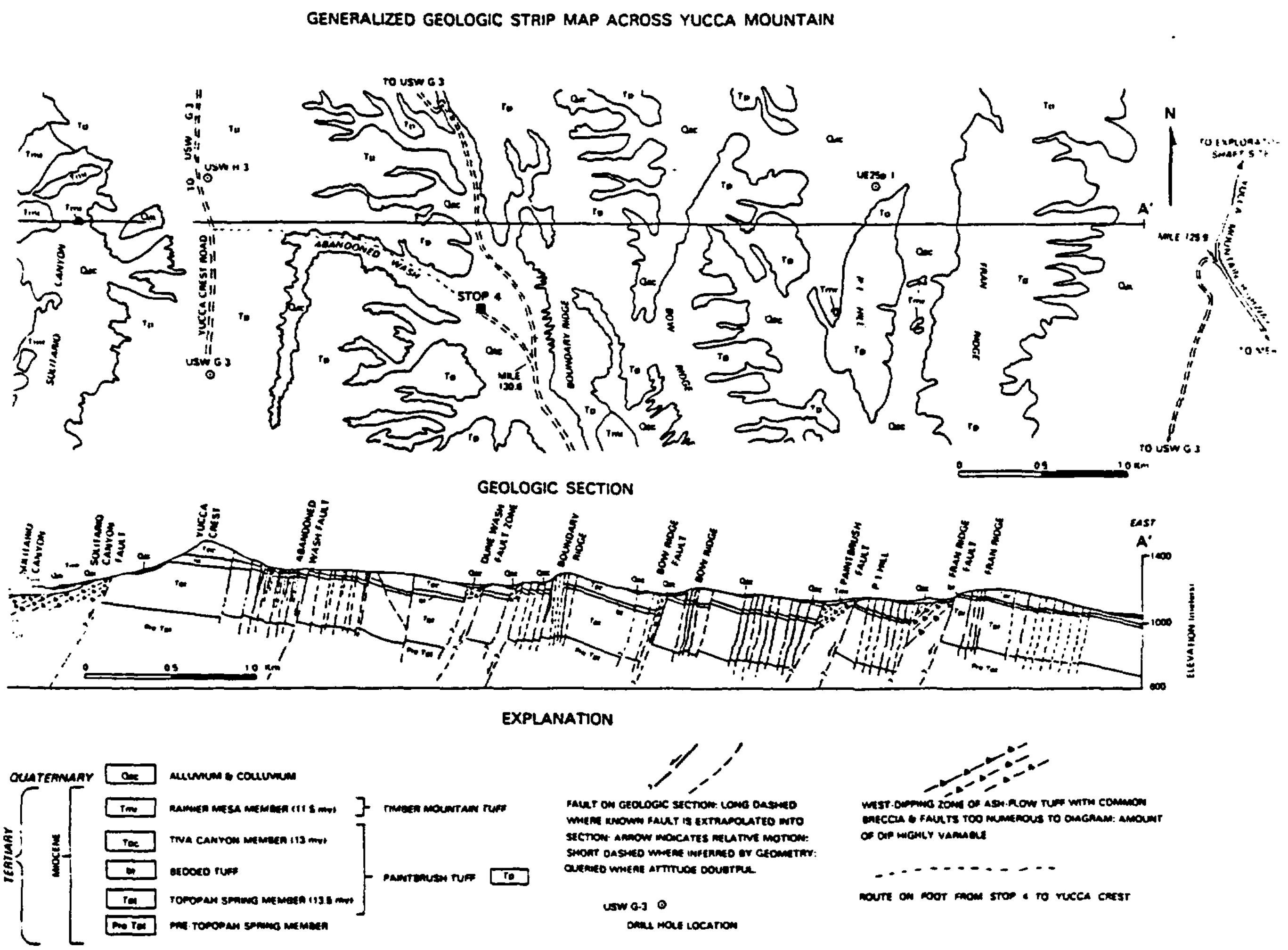

FIGURE 7: Geology of a part of the Yucca Mountain area (Stop 4).

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.

From the top of Yucca Mountain, you can see the late Precambrian and Paleozoic rocks of Bare Mountain and Plio-Pleistocene cinder cones and basalt lavas in Crater Flat. The steep east-facing front

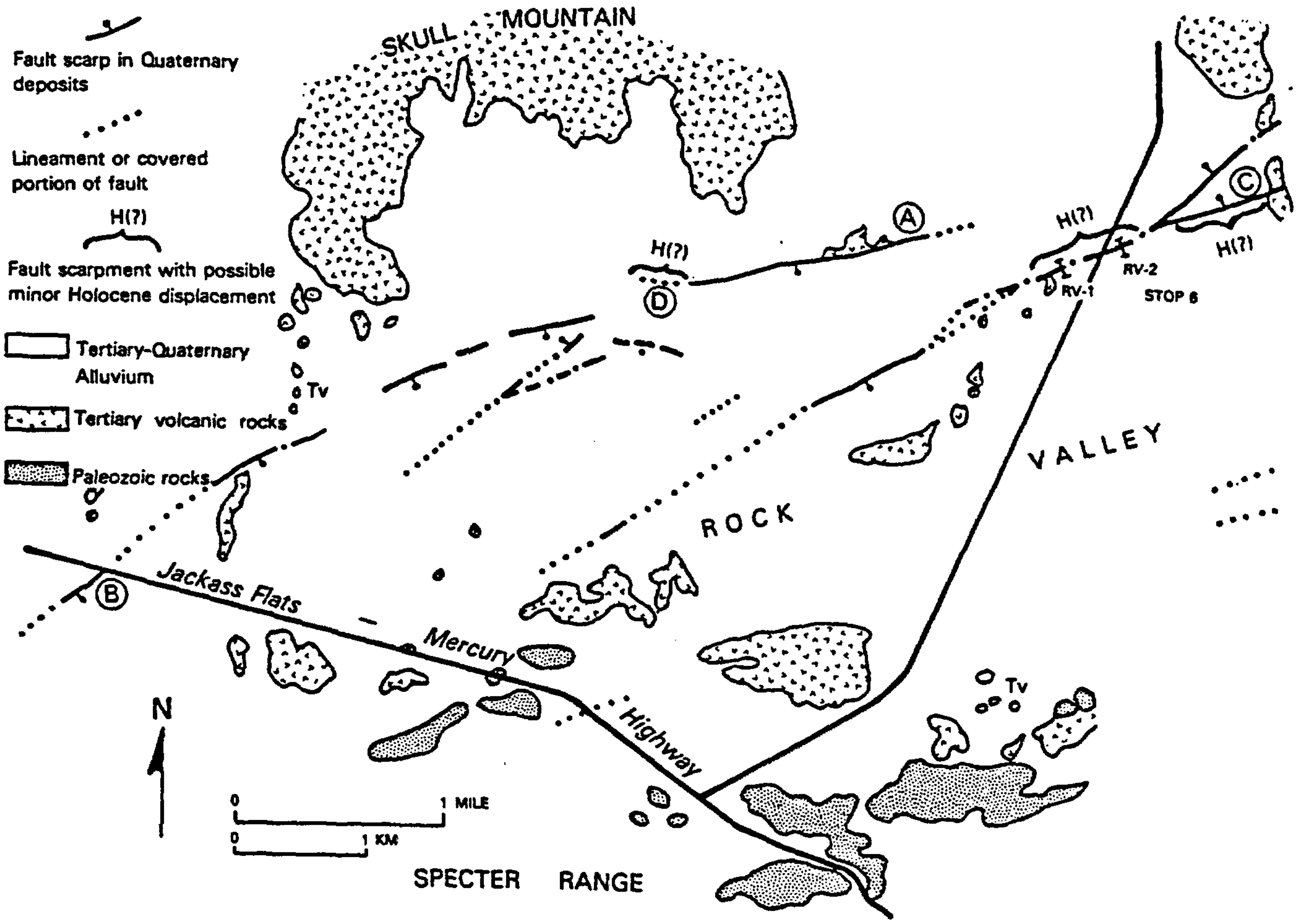

FIGURE 8: Sketch map of Quaternary faults in Rock Valley (Stop 6).

of Bare Mountain may be a major bounding fault that 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-G4."

145.0 STOP 5. POSSIBLE NUCLEAR WASTE REPOSITORY.
(Depending on time, this stop may be cancelled).

Exploratory Hole USW-G4 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; BREN (Bare Reactor Experiment-Nevada) 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

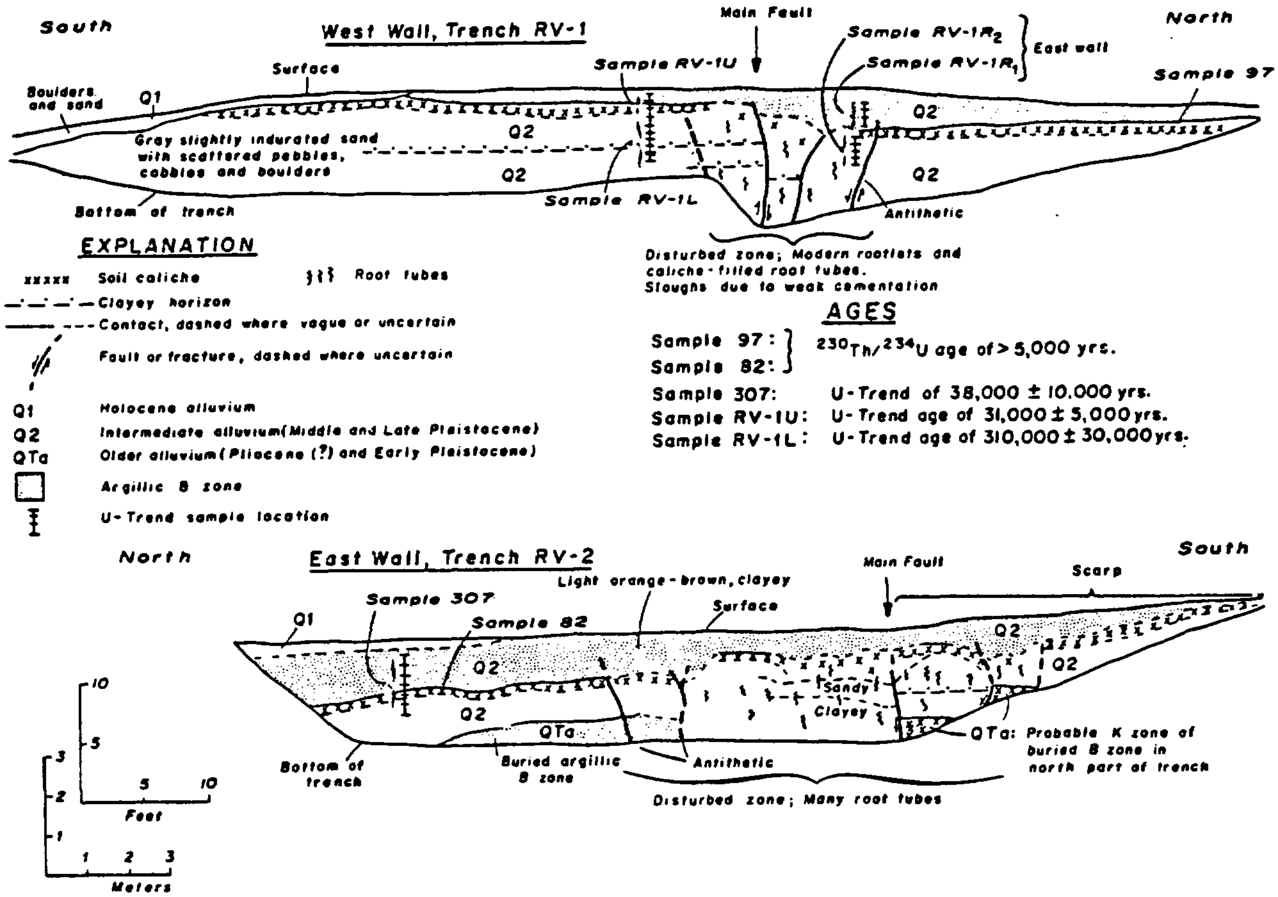

FIGURE 9: Profiles of trenches on Rock Valley fault zone (Stop 6).

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. ROCK VALLEY FAULT SYSTEM.

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 yrs. (Hoover and others, 1981). 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 yrs.; dates from the upper part of Q2 are about 35,000 years. Two samples of the laminar carbonate K horizon gave ages of greater than 5,000 yrs. 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 yrs., suggesting no reopening of the fracture and probably no major movement on the adjacent fault after 20,000 yrs. 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. ?), 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 yrs. 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 yrs. ago.

The younger event, shown by 0.3 - 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 - 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 yrs. 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. MERCURY, NEVADA.

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 U.S. Geological Survey (USGS) at the Nevada Test Site, 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, down-hole video tapes of selected drill holes, and 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 the Test Site, and secondary (diagenetic) minerals have been studied intensively for their capability inhibiting migration of radioactive nuclides. Examples of both types of work are described below. Petrographic exhibitsof 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 late 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 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).

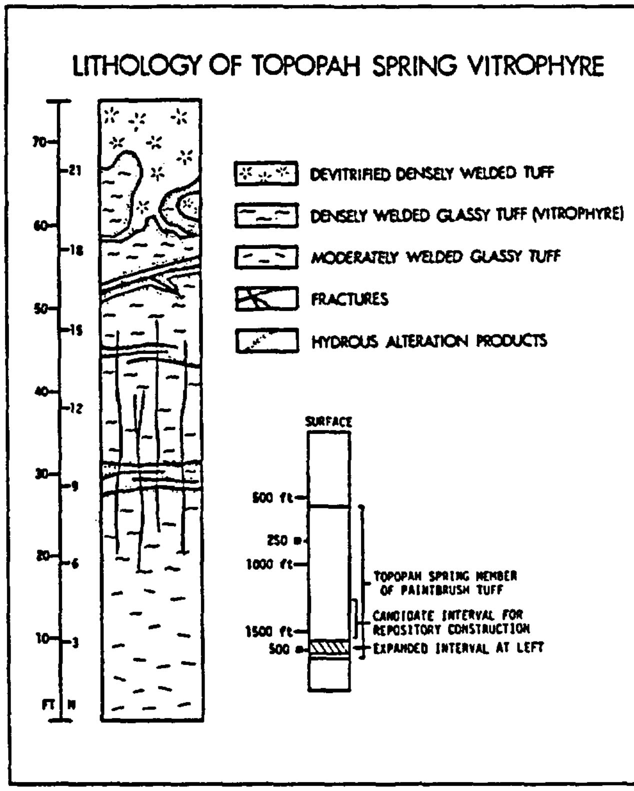

FIGURE 10: Lithology of Topopah Spring vitrophyre (Stop 7), generalized from drill holes on Yucca Mountain.

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

Mileage

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 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 4:00 consists of Ordovician through Mississippian rocks that form the southeast limb of the Spotted Range syncline. Tower Hills, at 4:00, are Devils Gate Limestone. Specter Range in distance, between 7:00 and 9:00, contains Cambrian through Devonian rocks, and a major thrust fault (Specter Range thrust) that brings Upper Cambrian and Ordovician rocks over middle and upper Paleozoic rocks, 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 Test Site 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. ORIENTATION STOP. Turn left off road at Pump Station No. 4.

Facing north and looking counter-clockwise: 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. old (R. F. Marvin, written commun., 1980). High peak on skyline is Bald Mountain in the Groom Range 80 km. to NNE. 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 Mississipian and Cambrian rocks overlain by Tertiary volcanics. 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 tuffaceous sedimentary rocks

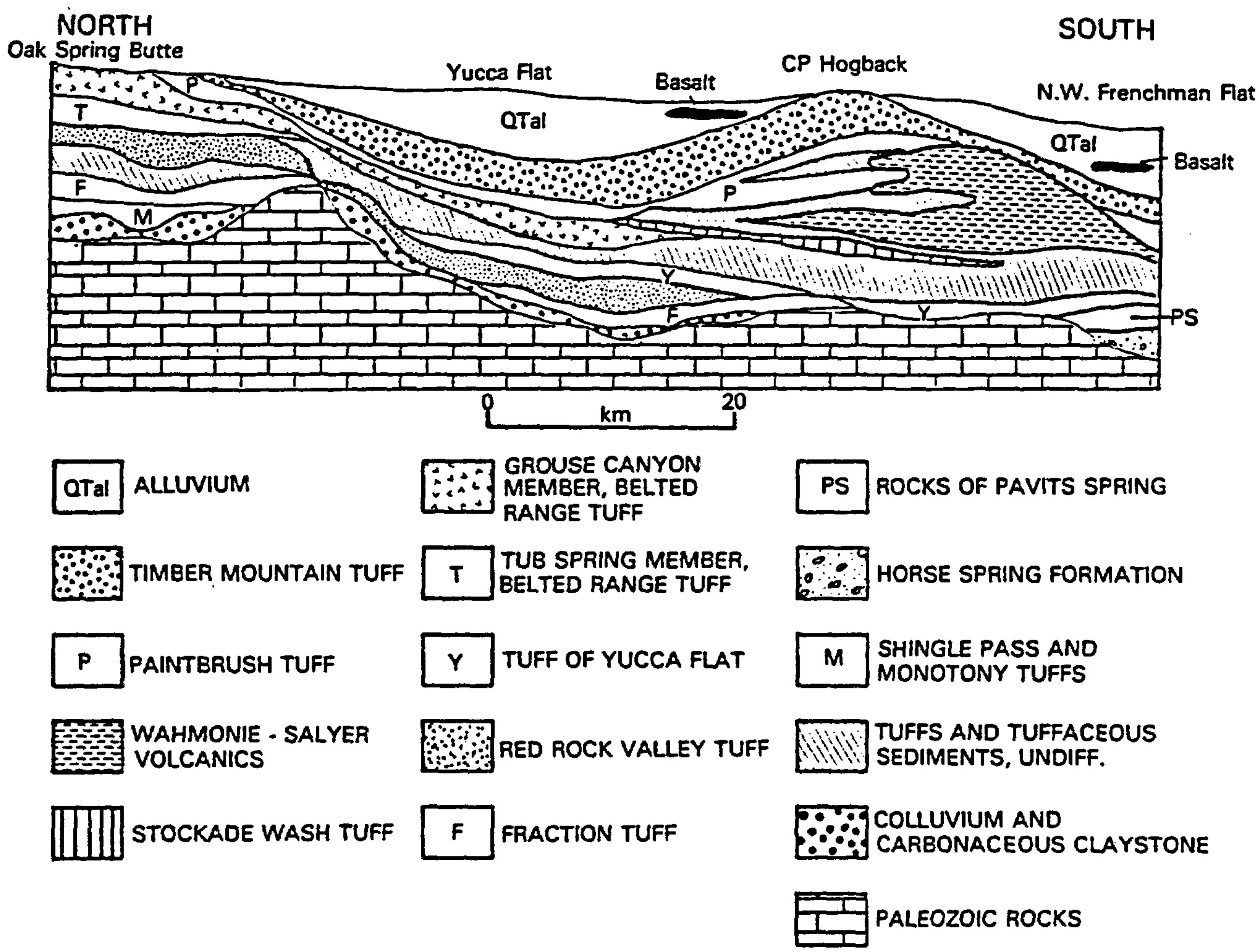

FIGURE 11: Diagrammatic cross-section from Oak Spring Butte to northwestern Frenchman Flat, Nevada Test Site, Stops 8 and 10.

of Pavits Spring Formation. 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 reentrant is vitrophyre lava of the Wahmonie Formation onlapped by Topopah Spring Member of the Paintbrush Tuff.

12.5 Turn left.

12.9 STOP 9. RADIONUCLIDE MIGRATION.

Turn left onto gravel road. Radionuclide Migration project site (Fig. 12). The RNM project was initiated in 1974 to study rates of the underground migration of radionuclides from explosion-modified zones at NTS. The Cambric event, detonated in Frenchman Flat in 1965 was chosen for the study for several reasons. The Cambric explosion cavity is within the NTS Area 5 water-supply aquifer, where leakage could have contaminated the water supply. Hydrologic modeling indicated that sufficient time had elapsed for ground water to fill the cavity and chimney to the preshot static water level, which is 73 m. above the detonation point. The Cambric detonation point is only 294 m. below ground surface, and thus the re-entry drilling and sampling operations were less difficult and expensive than for more deeply buried tests. The site is also far enough from the areas of active nuclear testing so that damage or interruption of the re-entry and sampling operations from those activities would be unlikely. Sufficient tritium (^{3}H or T) was present to provide an easily measurable tracer for water from the cavity region. The post-shot 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.

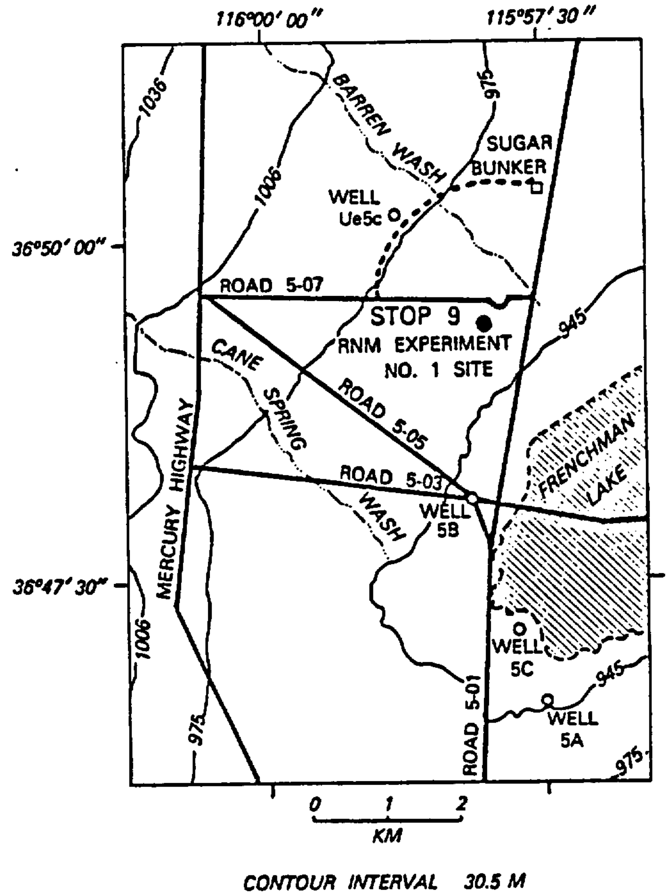

FIGURE 12: West-central Frenchman Flat, showing location of the RNM Experiment No. 1 site (Stop 9).

The RNM-25 satellite well has been pumped at the rate of about 600 gal./minute. 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 percent 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 ENE-trending Quaternary

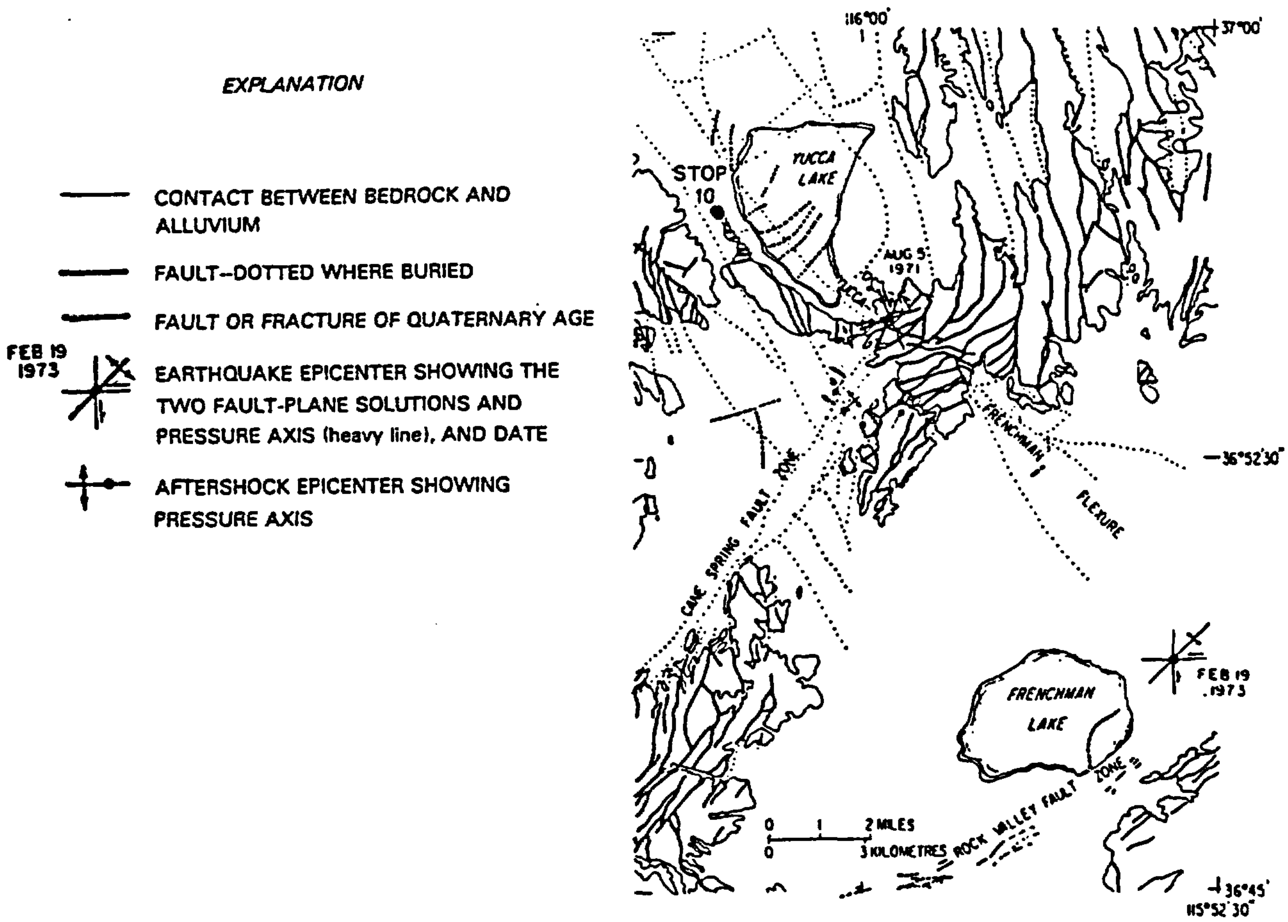

FIGURE 13: Southern Yucca Flat and Frenchman area, showing structural pattern, Quaternary faults and fractures, and location of earthquakes, their aftershocks, fault-plane solutions, and pressure axes (Stop 10).

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 late Wahmonie lava underlying vitrophyre of the Topopah Spring Member.

18.5 In distance at 10:30 is blue-gray Cambrian Bonanza King Formation Limestone thrust over brown argillites of the Mississipian Eleana Formation, overlapped by Tertiary volcanics.

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). Topopah Spring vitrophyre 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. 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

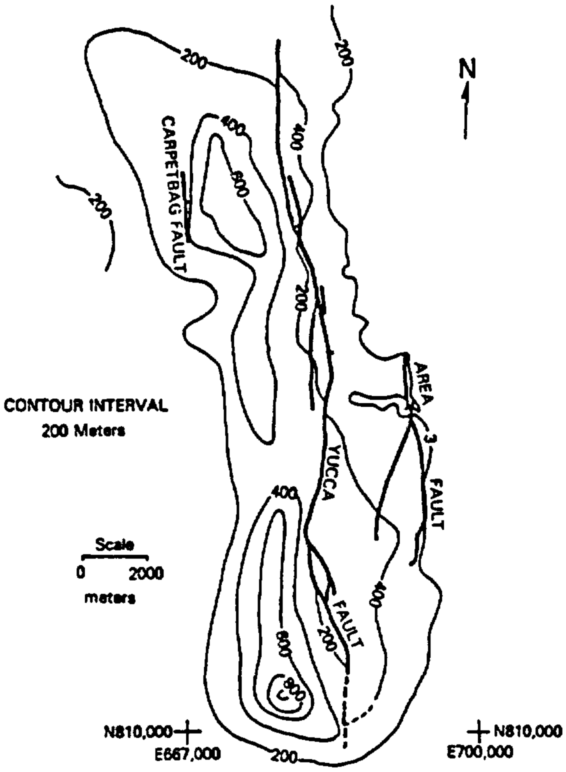

FIGURE 14: Isopach map of late Tertiary and Quaternary alluvium in Yucca Flat (Stop 10).

tests. Climb News Knob.

Facing northward, at 3:00 to 1:00 is Halfpint Range; at 1:30 Slanted Buttes is 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 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 late 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, 1983; Ander and Oldow, 1983; Ander, 1984), or between the north-trending Carpetbag fault and Yucca-Frenchman shear and flexure zone (W. J. Carr, in prep.). 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 years, 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

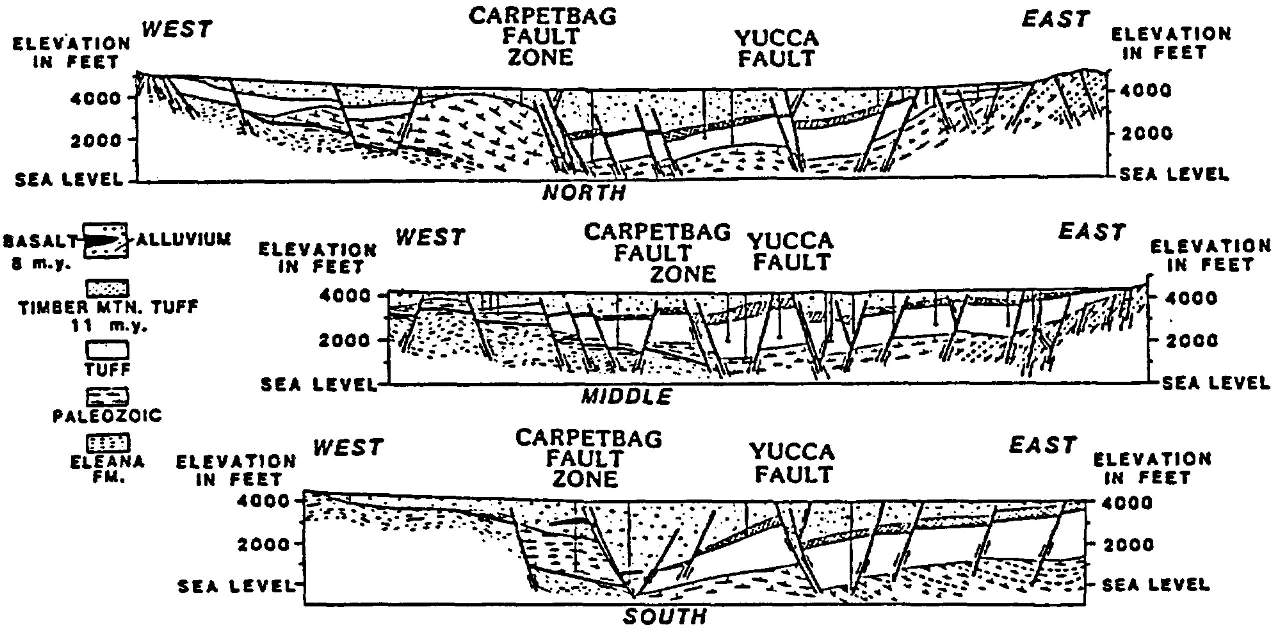

FIGURE 15: Geologic sections across Yucca Flat (Stop 10).

structural zone to the southwest, and a much lower rate of activity to the northeast. Before the present seismic network, two mediumsized 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 dessication 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 of they were caused by shrinkage resulting from dessication; (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 Mississipian Eleana Formation (Orkild, 1968; Stop 16).

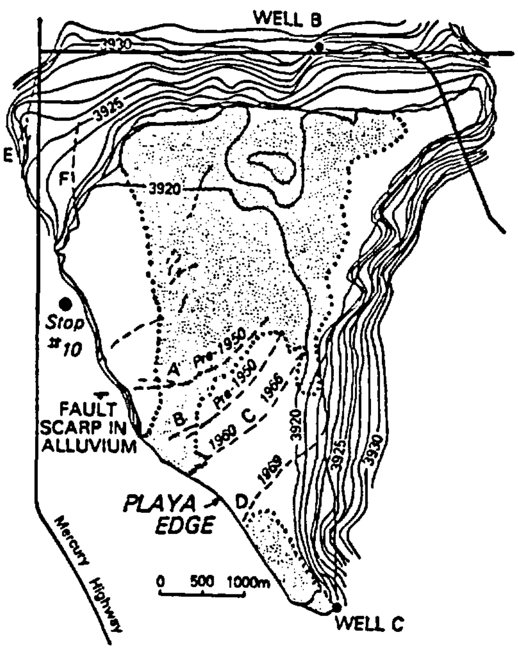

FIGURE 16: Map of Yucca Lake playa area showing cracks (lettered A to F) and detailed topography. Shaded area is apparently depressed with respect to unshaded areas, based on distribution of water in the lake in March 1973 (Stop 10).

28.0 Area 6 Birdwell casing yard.

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

31.8 Reynolds Electric Company drilling support yard.

33.1 At Y in road veer left onto Rainier Mesa Road.

45.5 East-facing Yucca Fault scarp at 3:00.

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

47.2 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 which traverse the length of Yucca Flat on the western side (D. L. Healey, unpublished gravity data). Average post-tuff dip-slip displacement is 600 m.; right-lateral motion of as much as 600 m. 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 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, 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 which dip 10° to the southeast and are bounded by low scarps at the toe of the slope. Trenching reveals that the ramps are shallow features which 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 groundwater 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 slope-wash post-date 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 to Holocene units described by Hoover and others (1981). The older units pre-dating fault movement have a thin K horizon with stages III to IV morphology and have uranium-trend dates of 270,000 to 310,000 yrsa. (J. N. Rosholt, written commun., 1983). Uranium-series dating of secondary carbonate along fractures brackets the displacement between 93,000 and 37,000 yrs. (Knauss, 1981), which correlates well with the lack of distinguishable fault scarps in the younger (Holocene?) gravels prior to nuclear testing in 1970.

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

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

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

51.7 Turn right to Sedan Crater.

52.1 STOP 12. CONTAINMENT GEOLOGY.

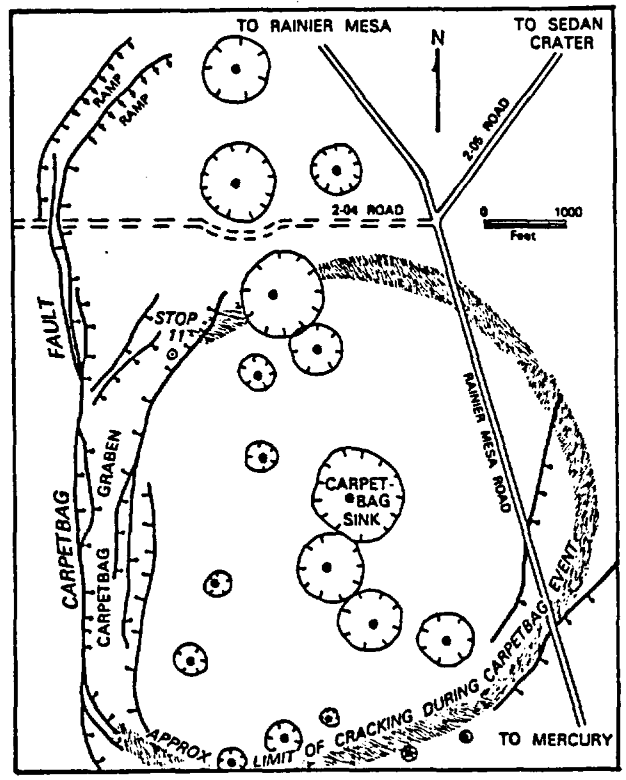

FIGURE 17: Carpetbag fault system (Stop 11).

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, non-condensible gas generation (CO_2), depth to the static water level, acoustic impedances and any features which are unusual. Adequate characterization often requires the drilling of 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 Department of Energy's panel of experts is the experiment allowed to proceed.

The explosive device is placed into a large rack which 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.

Peaceful nuclear explosions in the U.S., as encompassed in the Plowshare Program, began as a series of meetings and

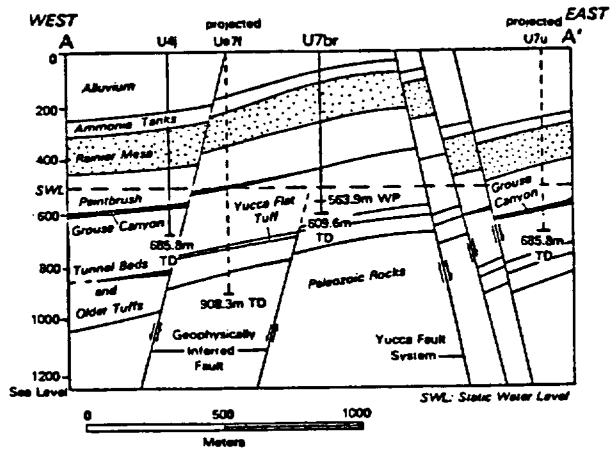

FIGURE 18: Geologic section through an emplacement site (Stop 12).

panels in 1956. Massive nonnuclear high-explosive excavation and fracturing experiments were conducted at the Nevada Test Site 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 5×10^6 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 2.45×10^{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.

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

54.1 Turn right on Road 2-07.

56.6 Turn right onto Rainier Mesa Road.

60.8 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 2/3 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.

62.5 Thrust fault between the Devonian Devils Gate limestone and Missippian Eleana on right.

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

64.3 Tuff/Paleozoic contact, very altered.

65.6 STOP 13. ORIENTATION.
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.

66.8 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, down-faulted to the west along outer ring fracture faults associated with the Timber Mountain caldera collapse.

67.3 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 downcutting.

69.3 Intersection with Pahute Mesa Road, continue straight ahead.

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

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

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

73.1 Contact between Grouse Canyon welded tuff and underlying Grouse Canyon airfall tuff.

74.8 Grouse Canyon airfall tuff thickens westward toward Split Ridge.

77.2 STOP 14. 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, 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 partway 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 Paintbrush equivalent other than the

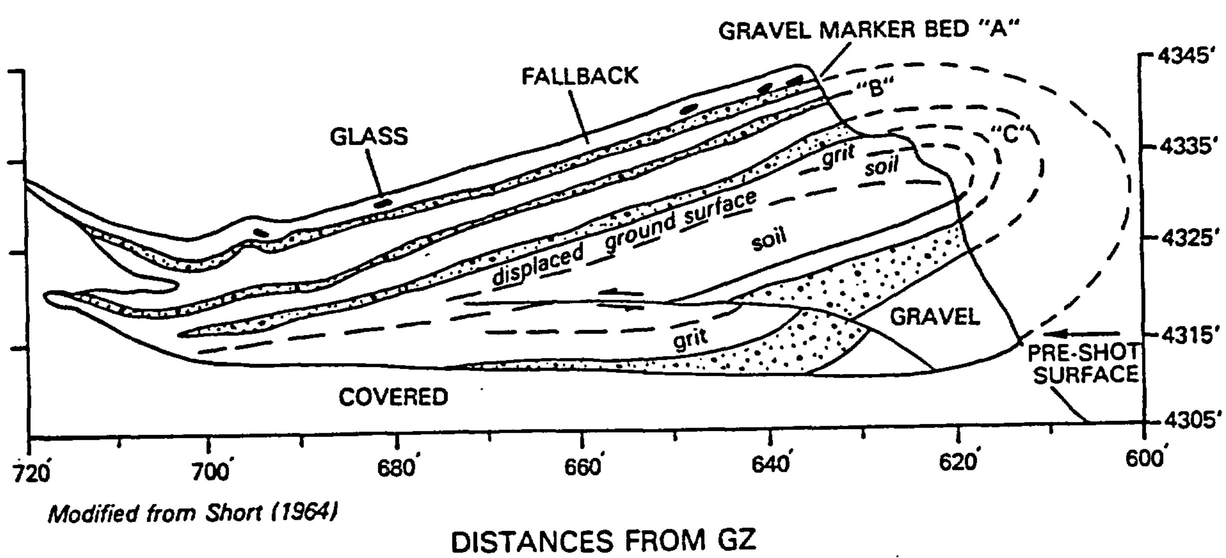

FIGURE 19: Geologic section through the Sedan Crater lip exposed in cross section trending N58°W from ground zero (Stop 12).

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 towards 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 of Orkild and others (1968). 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 volcanics containing Mg-rich mafic minerals are interbedded with the Belted Range Tuff.

Following cessation of comenditic volcanism, a sequence of calcalkaline 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.

85.2 Turn right (south) on Pahute Mesa Road.

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

86.4-87.4 Traverse alluvial caldera fill.

89.4 End of pavement.

89.5 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.-old basalt cinder cones and lavas of Buckboard Mesa. The basalts were erupted where Basin and Range faults intersect inner caldera ring fracture zone.

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

91.5 Unconformable contact and debris flows between Split Ridge lavas to 47 left and Ammonia Tanks tuff to right.

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

92.6 STOP 15. TIMBER MOUNTAIN CALDERA (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. 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).

95.6 Turn left onto Airstrip Road.

99.3 Turn right on Pahute Mesa Road.

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

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

103.5 Altered multi-colored tuffs and thin Grouse Canyon Member cut by minor fault crossing the road.

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

104.4 On left, contact between Red Rock Valley Tuff and Eleana Formation in road cut.

106.7 Highway parallels Syncline Ridge at 12:30 formed by Pennsylvanian Tippipah Limestone.

109.0 Pass the axial trace of Syncline Ridge, best exposed on right (south) side of bus, 1100 m. of Pennsylvanian 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.

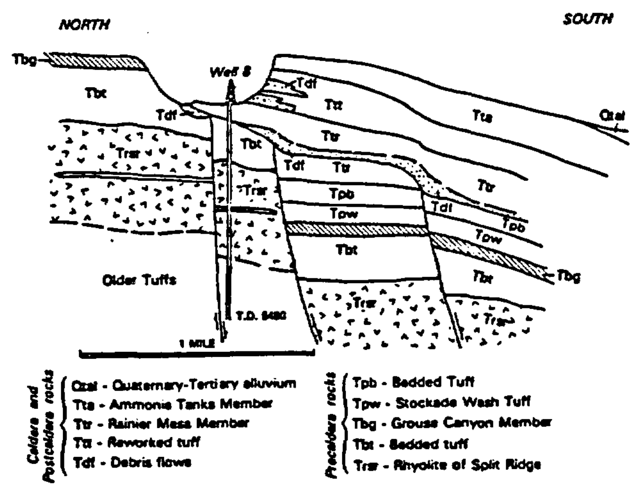

FIGURE 20: Sketch of geologic relations at Well 8 (Stop 15).

110.9 Turn right on Orange Road (Tippipah Highway).

116.2 Turn right on Mine Mountain Road.

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

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

118.7 Structure to left is old mercury retort.

119.5 STOP 16. MINE MOUNTAIN THRUST.

The route to this stop 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. 21). Overlook Point offers an excellent panorama of Mine Mountain thrust and of Yucca Flat.

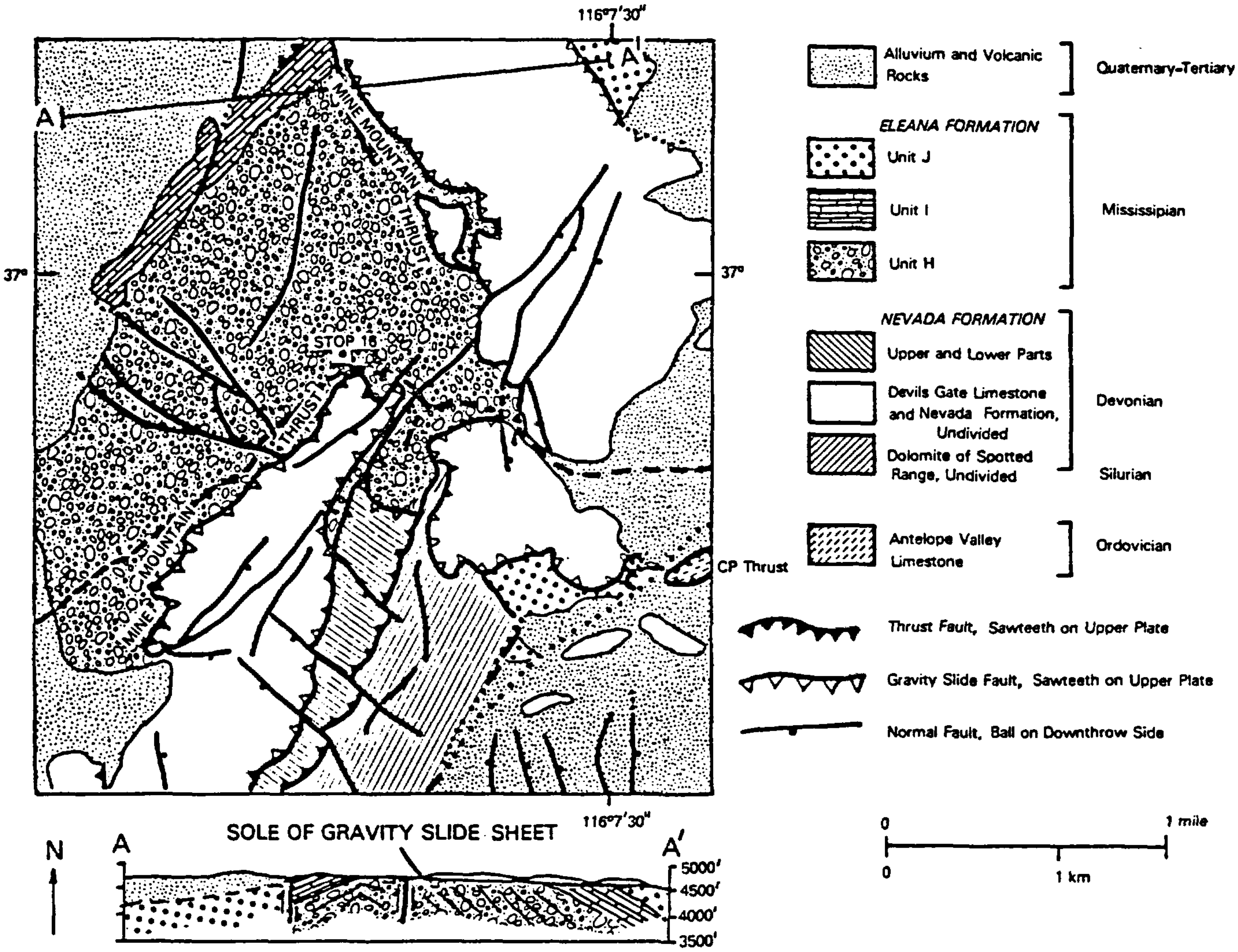

FIGURE 21: Geology in vicinity of Mine Mountain (Stop 16.)

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 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.).

122.8 Turn right on Tippipah Highway for return to Mercury.

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

REFERENCES

Ander, H. D., 1983, Ash-flow tuff distribution and fault patterns as indicators of late-Tertiary regional extension, Nevada Test Site: Proceedings Second Symposium on Containment of Underground Nuclear Explosions, Kirtland AFB, Albuquerque, NM, August 2-4, 1983, Lawrence Livermore National Laboratory CONF-830882, v. 1, Clifford Olsen, Compiler, p. 155-174.

_____ 1984, Rotation of late Cenozoic extensional stresses, Yucca Flat region, Nevada Test Site, Nevada, Ph.D. thesis: Houston, Rice University, 77 p.

_____, and Oldow, J. S., 1983, Late Cenozoic rotation of extensional stresses, Yucca Flat region, Nevada Test Site, Nevada (abs.): EOS Trans. Amer. Geophys. Union, v. 64, no. 45 (Fall Meeting Abstracts), p. 858.

Barnes, Harley, Ekren, E. B., Rogers, C. L., and Hedlund, D. L. 1982, Geologic and tectonic map of the Mercury Quadrangle, Nye and Clark Counties, Nevada: U.S. Geol. Survey Misc. Inv. Map I-1197, scale 1:24,000.

Broxton, D. E., Vaniman, D., Caporuscio, F., Arney, B., and Heiken, G., 1983, Detailed petrographic descriptions and microprobe data for drill holes USW-G2 and Ue25b-1H, Yucca Mountain, Nevada: Los Alamos National Laboratory report LA-9324-MS, 168 p.

Burchfiel, B. C., 1964, Precambrian and Paleozoic stratigraphy of Specter 52 Range quadrangle, Nye County, Nevada: Am. Assoc. Petroleum Geologists Bull., v. 48, p. 40-56.

Byers, F. M. Jr., Carr, W. J., Christiansen, R. L., Lipman, P. W., Orkild, Paul, and Quinlivan, W. D., 1976a, Geologic map of Timber Mountain caldera, Nye County, Nevada: U.S. Geol. Survey Misc. Geol. Inv. Map I-891, scale 1:48,000.

_____, Carr, W. J., Orkild, Paul P., Quinlivan, W. D., and Sargent, K. A., 1976b, Volcanic suites and related cauldrons of Timber Mountain-Oasis Valley Caldera complex, southern Nevada: U.S. Geol. Surv. Prof. Paper 919, 70 p.

_____, Carr, W. J., Orkild, Paul P., Scott, R. B., and Warren, R. G., 1983, Volcano-tectonic relations and some petrologic features of the Crater Flat Tuff, southwestern Nevada (abs.): Geol. Soc. Amer. Abstracts with Programs, v. 15, n. 5, p. 280.

Carr, W. J., 1964, Structure of part of the Timber Mountain dome and caldera, Nye County, Nevada; in Geological Survey research 1964: U.S. Geol. Survey Prof. Paper 501-B, p. B16-B19.

_____, and Quinlivan, W. D., 1968, Structure of Timber Mountain resurgent dome, Nevada Test Site: Geol. Soc. Amer., Mem. 110, p. 99-108.

_____ 1974, Summary of tectonic and structural evidence for stress orientation at the Nevada Test Site: U.S. Geol. Survey Open-File Report 74-176, 53 p.

_____ 1982, Volcano-tectonic history of Crater Flat, southwestern Nevada, as suggested by new evidence from drill hole USW-VH-1 and vicinity: U.S. Geol. Survey Open-file Report 82-457, 23 p.

_____, Byers, F. M., Jr., and Orkild, P. P., 1984, Stratigraphic and volcano-tectonic relations of Crater Flat Tuff and some older volcanic units, Nye County, Nevada: U.S. Geol. Survey Prof. Paper 1323 (in press).

Crowe, B. M., and Carr, W. J., 1980, Preliminary assessment of the risk of volcanism at a proposed nuclear waste repository in the southern Great Basin, Nevada and California: U.S. Geol. Survey Open-File Report 80-357, 15 p.

_____, Johnson, M. E., and Beckman, R. J., 1982, Calculation of the probability of volcanic-disruption of a high-level radioactive waste repository within southern Nevada, USA: Radioactive Waste Management and the Nuclear Fuel Cycle, v. 3(2), p. 167-190.

_____, Vaniman, D. T., and Carr, W. J., 1983, Status of volcanic hazard studies for the Nevada Nuclear Waste Storage Investigations: Los Alamos National Laboratory report LA-9325-MS, 47 p.

_____, Self, S., Vaniman, D., Amos, R., and Perry, F., 1983, Aspects of potential magmatic disruption of a high-level radioactive waste repository in southern Nevada: Jour. Geol., v. 91, p. 259-276.

Daniels, W. R. (ed.), 1983, Laboratory and field studies related to the radionuclide migration project: Los Alamos National Laboratory Rept. LA-9691-PR, 63 p.

Fleck, R. V., 1970, Age and possible origin of the Las Vegas Valley shear zone, Clark and Nye Counties, Nevada: Geol. Soc. Amer. Abs. with Programs (Rocky Mtn. Sec.), v. 2, no. 5, p. 333.

Gile, L. H., Peterson, F. F., and Grossman, R. B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.

Hildreth, W., 1981, Gradients in silicic magma chambers: implications for lithospheric magmatism: Jour. Geophys. Res., v. 86(B11), p. 10153-10192.

Hoover, D. L., 1968, Genesis of zeolites, Nevada Test Site: Geol. Soc. Amer. Mem. 110, p. 275-284.

_____, Swadley, W. C., and Gordon, A. J., 1981, Correlation characteristics of surficial deposits with a description of surficial stratigraphy in the Nevada Test Site region: U.S. Geological Survey Open-File Report 81-512, 27 p.

Knauss, K. G., 1981, Dating faults and associated Quaternary material from the Nevada Test Site using uranium-series methods: Livermore, California, Lawrence Livermore Laboratory, UCRL-53231, 51 p.

Levy, S. S., 1983, Studies of altered vitrophyre for the prediction of nuclear waste repository-induced thermal alteration at Yucca Mountain, Nevada: (abs) Materials Research Society 1983 Annual Meeting Final Program and Abstracts, p. 222.

Longwell, C. R., 1974, Measure and date of movement on Las Vegas Valley shear zone, Clark County, Nevada: Geol. Soc. Amer. Bull., v. 85, p. 985-990.

Marvin, R. F., Byers, F. M., Jr., Mehnert, H. H., Orkild, Paul P., and Stern, T. W., 1970, Radiometric ages and stratigraphic sequence of volcanic and plutonic rocks, southern Nye and western Lincoln Counties, Nevada: Geol. Soc. Amer. Bull., v. 81, p. 2657-2676.

McKeown, F. A., Healey, D. L., and Miller, C. H., 1976, Geologic map of the Yucca Lake quadrangle, Nye County, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-327, scale 1:24,000.

Moncure, G. K., Surdam, R. C., and McKague, H. L., 1981, Zeolite diagenesis below Pahute Mesa, Nevada Test Site: Clays and Clay Minerals, v. 29, p. 385-396.

Noble, D. C., Sargent, K. A., Mehnert, H. H., Ekren, E. B., and Byers, F. M., Jr., 1968, Silent Canyon volcanic center, Nye County, Nevada: Geol. Soc. America Memoir 110, p. 65-76.

Orkild, Paul, 1982, Geology of the Nevada Test Site, <u>in</u> Proceedings First Symposium on Containment of Underground Nuclear Explosions, Monterey, CA, August 26-28, Los Alamos National Laboratory Report LA-9211-C, B. C. Hudson, E. M. Jones, C. E. Keller, and C. W. Smith, compilers, p. 323-338.

_____ 1968, Geologic map of the Mine Mountain Quadrangle, Nye County, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-746, scale 1:24,000.

_____, Byers, F. M. Jr., Hoover, D. L., and Sargent, K. A., 1968, Subsurface geology of Silent Canyon Caldera, Nevada Test Site, Nevada: Geol. Soc. America Memoir 110, p. 77-86.

_____, Sargent, K. A., and Snyder, R. P., 1969, Geologic map of Pahute Mesa, Nevada Test Site and vicinity, Nye County, Nevada: U. S. Geol. Survey Map I-567, scale 1:48,000.

Sargent, K. A., McKay, E. J., and Burchfiel, B. C., 1970, Geologic map of the Striped Hills quadrangle, Nye County, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-882, scale 1:24,000.

_____, and J. H. Stewart, 1971, Geologic map of the Specter Range NW Quadrangle, Nye County, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-884.

Short, N. C., 1964, nuclear explosions, craters, astroblemes, and cryptoexplosion structures: University of California Report UCRL-7787, 75 p.

Stewart, J. H., 1967, Possible large right-lateral displacement along fault and shear zones in the Death Valley-Las Vegas area, California and Nevada:

Geol. Soc. America Bull., v. 78, p. 131-142.

Vaniman, D. T. and Crowe, B. M., 1981, Geology and petrology of the basalts of Crater Flat: Applications to volcanic risk assessment for the Nevada Nuclear Waste Storage Investigations: Los Alamos National Laboratory report LA-8845-MS.

_____, Crowe, B. M., and Gladney, E. S., 1982, Petrology and geochemistry of hawaiite lavas from Crater Flat, Nevada: Contrib. Mineral. Petrol., v. 80, p. 341-357.

_____, Bish, D., Broxton, D., Byers, F., Heiken, G., Carlos, B., Semarge, E., Caporuscio, F., and Gooley, R., In press., Variations in authigenic mineralogy and sorptive zeolite abundance at Yucca Mountain, Nevada, based on studies of drill cores USW GU-3 and G-3: Los Alamos National Laboratory report LA-9707-MS.

Warren, R. G., 1983a, Geochemical similarities between volcanic units at Yucca Mountain and Pahute Mesa: Evidence for a common magmatic origin for volcanic sequences that flank the Timber Mountain Caldera, In Proceedings Second Symposium on Containment of Underground Nuclear Explosions, Kirtland AFB, Albuquerque, NM, August 2-4, 1983, Lawrence Livermore National Laboratory CONF-830882, v. 1, Clifford Olsen, compiler, 213-244.

_____ 1983b, Geochemical similarities between volcanic units at Yucca Mountain and Pahute Mesa: Evidence for a common magmatic origin for volcanic sequences that flank the Timber Mountain Caldera: EOS Trans. Am. Geophys. Union, v. 64, no. 45 (Fall Meeting Abstracts), p. 896.

Publication authorized by the Director, United States Geological Survey.

HYDROGEOLOGY OF THE NEVADA TEST SITE AND SOUTHERN AMARGOSA DESERT (FIELD TRIP 21)

Leaders: JOHN W. HESS and ROGER L. JACOBSON, Desert Research Institute, Reno

Contributors: CLINTON C. CASE, PAUL R. FENSKE, RICHARD H. FRENCH, JOHN W. HESS, ROGER L. JACOBSON, MARTIN D. MIFFLIN, and STEPHEN W. WHEATCRAFT, Desert Research Institute, Reno

INTRODUCTION

This trip was formulated to present a broad overview of the hydrogeology of the Nevada Test Site (NTS) and the Southern Amargosa Desert which is thought to be the discharge area for the regional ground-water flow system encompassing part of the NTS. There has been much interest in the hydrogeology of the area because of the potential of radionuclide migration away from the site, due to underground nuclear testing and the potential Yucca Mountain High Level Nuclear Waste Repository which might be sited on the western edge of the NTS.

The first day field trip begins with a tour of the NTS starting in Las Vegas and ending in Beatty, Nevada where we will spend the night. The next day will be a trip to the Southern Amargosa Desert ending in Las Vegas. Fig. 1 is a simplified map of the field trip.

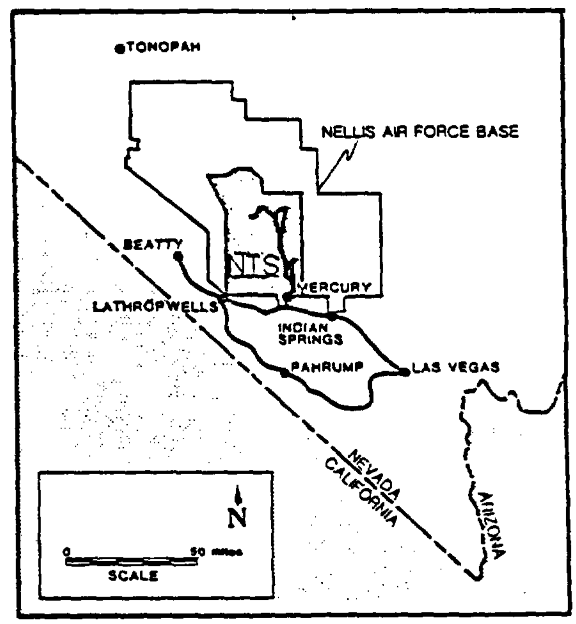

FIGURE 1 MAP OF FIELD TRIP AREA

LOCATION

The Nevada Test Site is located in Nye County in southern Nevada, with its southernmost point about 100 km. northwest of Las Vegas. The site contains 3,500 sq. km. of federally-owned land with restricted access.

The Nevada Test Site is bordered on three sides by 10,700 sq. km. of land comprising the Nellis Air Force Range, another federally-owned, restricted area (see Fig. 1). This buffer zone varies from 24-104 km. between the test area and land that is open to the public. A northwestern portion of the Nellis Air Force Range is occupied by the Tonopah Test Range, an area of 1,615 sq. km. The combination of the Tonopah Test Range, the Nellis Air Force Range, and the Nevada Test Site is one of the largest unpopulated land areas in the United States, comprising some 15,815 sq. km.

Fig. 2 shows the general layout of the Nevada Test Site and identifies some of the areas within the site. The shaded areas indicate principal areas used for underground testing.

Mercury is the main base camp at NTS. The camp provides general support facilities and overnight accommodations for 960 persons.

HISTORICAL BACKGROUND OF NTS

Use of the NTS areas prior to 1951 mainly comprised mining, grazing, and hunting. Two inactive mining districts, Oak Springs

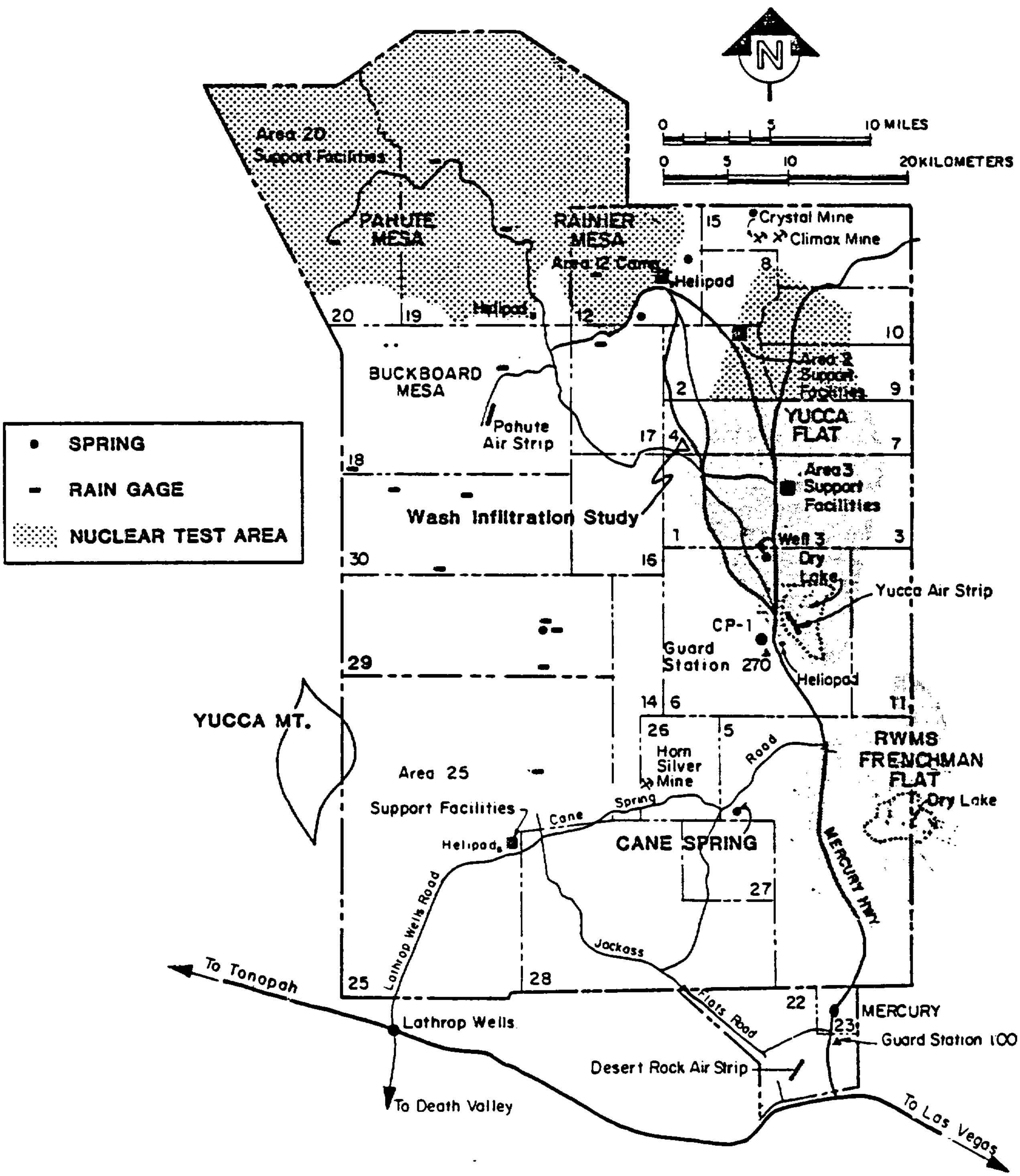

FIGURE 2 NEVADA TEST SITE

and Wahmonie, lie wholly or partially within the borders of the NTS. Oak Spring District occupied part of the northeast corner of the test site and included at least two onsite properties, the Climax Mine and the Crystal Mine, when the NTS was established (Area 15, Fig. 2). Prospecting and exploration started before 1905, and numerous small pits, shafts, and tunnels at higher elevations remain as evidence of sporadic activity which continued until NTS was established. Most of the prospects are at locations showing slight mineralization and low values in copper, lead, silver, gold, or mercury.

In 1937, low-grade tungsten ore was found in the Oak Spring mining district near the northeast corner of NTS. This small deposit was outlined as Climax and Crystal ore bodies (Fig. 2) by drilling and exploration conducted in 1940. Significant production of ore did not occur until 1956 when high tungsten prices permitted economic extraction of most of the ore. After 10 yrs. of co-use the mining claims were acquired by the government through routine condemnation procedures and the owners reimbursed. The workings have since remained in disuse.

The Wahmonie District, located in south central NTS, was prospected about 1905 for gold and silver ores. No production occurred until 1928 when a high grade silver-gold ore was rediscovered at the Horn Silver mine located in Area 26 (Fig. 2). This resulted in minor shipments of ore and caused an influx of 1,500 people into Wahmonie. However, after several shafts and extensive prospecting in the area revealed no additional ore finds, interest rapidly waned and the town was abandoned by the summer of 1929.

In addition to these developments, there is evidence of sporadic prospecting throughout the Nevada Test Site. Disruption of the landscape by mining and prospecting was locally severe, but the total impact of these activities on the environment has been slight. Extensive geologic investigations made by the U.S. Geological Survey using samples taken from exploratory drill holes, emplacement holes, and tunnels in the areas used for nuclear testing have revealed no mineral deposits which would be economically recoverable considering today's mineral requirements. Other than the deposits in the mining districts mentioned above, no additional qualifying mineral deposits have been found.

Prior to 1955 the NTS area was used for cattle grazing, and waterholes were developed and cabins and corrals built at several points on the site. Impact of the grazing industry on the environment, prior to the establishment of the NTS, was evidently small and is now indiscernible.

In the years immediately following World War II, nuclear weapons tests were conducted in the atmosphere or underwater. Before 1951, all of this work was done at remote Pacific island sites. When weapons development was accelerated in 1949 and 1950 in response to the national defense policy it became increasingly clear that if nuclear weapons could be tested safely within the continental boundaries, weapons development lead times would be reduced and considerably less expense incurred. At that time, a number of sites throughout the continental United States, including Alaska, were considered on the basis of low population density, safety, favorable year-round weather conditions, security, available labor sources, reasonable accessibility including transportation routes, and favorable geology. Of all the factors, public safety was considered the most important. It was determined that under careful controls, an area within what is now the Nellis Air Force Range could be used for relatively low yield nuclear detonations with full assurance of public safety.

Originally, 1,760 sq. km. were withdrawn on February 19, 1952, for nuclear testing purposes. This resulted in the formation of approximately the eastern half of the present Nevada Test Site. The predominant features of this area are the closed drainage basins of Frenchman Flat and Yucca Flat where the early atmospheric tests were conducted. The main Control Point was located and remains on the crest of Yucca Pass between these two basins (Fig. 2). Additional land withdrawals in 1958, 1961, and 1964 added to the site, and with the use of the Pahute Mesa area acquired in 1967, provide its present size of about 3,500 sq. km.

Although the NTS was originaly selected to meet criteria for atmospheric tests, it also has proved satisfactory for underground tests. For tests of up to one megaton and for those of a somewhat higher yield, the NTS continues to be the most suitable area and provides an established facility in a location remote from population centers. The geologic media at the explosion sites permit the placement of nuclear devices at sufficient depth for proper containment and control of radiation. The water table is relatively deep and water movement is very slow. Weather conditions permit a year-round testing program.

Construction of the Nevada Test Site facilities began on January 1, 1951. Operation RANGER was the first series of tests for which the Nevada Test Site was utilized. The first test was of a one-kiloton device which was airdropped and detonated on January 27, 1951, in Frenchman Flat.

After 1951, nuclear test series were carried out alternately at the Nevada Test Site and at Pacific test locations. Testing at that time was conducted on an intermittent task force basis at both the Nevada Test Site and in the Pacific and continued in that mode until October, 1958.

On October 31, 1958, the United States and the USSR entered into a voluntary test moratorium which lasted until the USSR resumed testing on September 1, 1961. After resuming the U.S. test program at the NTS on September 15, 1961, the Atomic Energy Commission (AEC) revised its mode of operations from an intermittent annual activity to a continuing year-round program.

From 1951 until early 1962, all nuclear tests at the NTS were under management of the AEC's Albuquerque Operations Office. Because of the significantly increased activities resulting from the resumption of weapons testing in the fall of 1961, the Nevada Operations Office (NV) was established in Las Vegas on March 6, 1962. Since the establishment of the Nevada Test Site in 1951 up until the beginning of January 1983, there have been around 750 announced nuclear tests conducted at the Nevada Test Site. All atmospheric tests and Plowshare program tests conducted at the Nevada Test Site have been announced. Underground nuclear tests that may cause significant ground motion are announced in advance to news media as a safety precaution, so that persons in communities nearby may avoid being in a hazardous location at the time of detonation. Other tests are announced after they have been conducted. Some tests with low yields are not announced.

If cratering experiments are excluded, all but four (small surface tests) of the atmospheric detonations occurred prior to the 1958 moratorium. The first full-scale nuclear detonation, which was designed to contain all radioactivity underground, was fired at the Nevada Test Site in 1957 in a sealed tunnel. Since late 1962, the United States has conducted all of its nuclear weapons tests underground.

A nuclear cratering device, code named DANNY BOY, was detonated on Buckboard Mesa on the western portion of the test site in 1962 as a military experiment for the Department of Defense. Three of the four small atmospheric (surface) tests mentioned above were also conducted on the flats just to the east of Buckboard Mesa and one, SMALL BOY, was conducted in Frenchman Flat for the Department of Defense (DOD) in 1962. Thereafter, nuclear cratering tests were conducted as part of the peaceful applications (Plowshare) program. There have been six such experiments, three of which are mentioned here. The first and largest was SEDAN, a 100-kiloton explosion on July 6, 1962, which created a huge crater in the alluvium of Area 10 roughly 340 m. across and 98 m. deep.

Nuclear tests have been conducted for a variety of reasons: 1) improvement of long-range seismic detection techniques; 2) conduction of joint US-UK tests of United Kingdom devices; 3) development tests for potential peaceful applications (Plowshare); 4) research to collect scientific data to better understand the physical principles involved in nuclear explosions; 5) exploration of new and untried designs for a given weapon concept; 6) determining the interaction between two or more demonstrated components; 7) proof testing of actual warhead designs; 8) conduction of safety tests on certain designs to test the vulnerability to possible accidents; and 9) conduction of weapons effects tests for the Department of Defense (for the most part in tunnels) to determine the effects produced by specific weapon outputs upon various military systems and components.

Although the major effort at the Nevada Test Site has been in nuclear weapons-related testing, the activities have included a variety of both nuclear and non-nuclear projects wherein the Department of Energy (DOE) laboratories, DOE contractors, as well as other government agencies and their contractors have taken advantage of the facilities available, the climate, the remoteness, and the controlled access of the test site.

As a part of the program to develop methods for predicting building response to ground motion, two identical four-story reinforced concrete test structures were constructed in Area 1. Between 1966 and 1973, structural response measurements were recorded for 42 underground nuclear experiments. These structures were also subjected to a series of low-amplitude dynamic tests for gathering engineering data on the response of structures to ground motion both with and without non-structural infill walls and partitions. By 1973, after sufficient low-amplitude data had been accumulated, high-amplitude, destructive level testing was conducted on one of these structures. These tests were carried out in 1974.

A herd of range cattle has been maintained onsite since the mid-1950's and an experimental dairy farm in Area 15 had been operated until early 1980's. Levels of radionuclides in these experimental herds were monitored as part of the routine radiological surveillance program. Data from experiments with animals taken from these herds are being used to improve human-dose prediction models and to furnish information on the effectiveness of protective actions which may be taken to reduce the amounts of radionuclides getting into human food under various contaminating situations.

In addition to its other responsibilities, beginning in FY 1974, the Nevada Operations Office became responsible for the custody and administration of the geographical area and the facilities at the former Nuclear Rocket Development Station (NRDS) (Area 25). The NRDS occupied the southwest corner of the Nevada Test Site (see Fig. 2). Area 25 contains some $140 million of specialized facilities: (1) nuclear reactor/engine/nuclear furnace test stands (known as ETS-1, Test Cell C, and Test Cell A); (2) engine maintenance, assembly, and disassembly building (known as E-MAD); (3) reactor maintenance, assembly, and disassembly building (known as R-MAD); (4) radioactive material storage facility (known as RMSF); and (5) other support facilities.

Twenty experimental reactor/nuclear engine/nuclear furnace tests have been conducted in this area between 1959 and termination of program in 1973.

In Area 26 (also known as Area 401), the Lawrence Livermore National Laboratory conducted six experimental tests involving development of a nuclear reactor for a ramjet engine as a part of Project Pluto. A radioactive leach field was constructed adjacent to the disassembly building to handle radioactive liquids resulting from these tests. This field is some 75 m. by 80 m. occupying an area of about 6,000 sq. m., and appropriately fenced and marked.

CLIMATE

The NTS area lies in the most arid portion of Nevada where average rainfall in the valleys range from 7.0 cm. to 15.0 cm. and up to 25 cm. per yr. on the ridges (Winograd and Thordarson, 1975). Mean maximum daily temperatures for the NTS valley region in January ranges from 5°C to 10.5°C and in July ranges from 32°C to 41°C. Temperatures are 3 to 9° lower on the ridges and mesas. Relative humidity ranges from 10 to 30 percent in summer and 20 to 60 percent in winter.

Most precipitation on the NTS falls during the winter and summer months. Summer convective storms occur over 2-3 sq. km. and are very intense, in contrast to winter storms which may cover the entire NTS and are less intense (Winograd and Thordarson 1975).

GEOLOGICAL SETTING

The following Geological and Hydrogeological setting sections were referenced from Winograd and Thordarson (1975), which is in part a compilation of other work, and Fenske (1978).

The NTS lies in a miogeosynclinal belt of the Cordilleran geosyncline. During the Precambrian through the Paleozoic era up to 11,000 m. of sediments were deposited. Except for a few, scattered and small igneous intrusive masses, sedimentary Mesozoic rocks are not present on the NTS. In Late Miocene and Early Pliocene the region underwent a period of volcanism emplacing 4,000 m. of rocks originating from caldera centers. The Quaternary system is represented by an erosional period resulting in detritus of up to 600 m. thick filling in the low lying areas.

Two major orogenies have deformed the region. The first occurred in late Mesozoic, and resulted in major folding and thrust faulting of the Precambrian and Paleozoic rocks. In the middle to late Cenozoic the second period of deformation occurred causing major block faulting forming the basin and range structure. During both orogenies strike slip faults were common with displacements measured up to several miles long.

The Precambrian and Paleozoic sediment pile is divided into 16 formations. The Precambrian and lower Cambrian are comprised mainly of quartzite intermixed with minor amounts of siltstone and dolomite. Middle Cambrian to middle Ordovician is dominated by limestones interbedded with some claystones, with the upper Ordovician to upper Devonian consisting of dolomite and minor amounts of quartzite. Mississippian and Pennsylvanian rocks are largely argillites and limestone respectively.

The Cenozoic rocks are divided into two systems, Tertiary and Quaternary, which contain twelve formations. Volcanics and associated sedimentary rocks make up the bulk of Tertiary sediments while Quaternary sediments are chiefly alluvial valley fill. The Oligocene and lower Miocene are composed of freshwater limestones, sandstones, and siltstones while upper Miocene rocks are chiefly ash fall tuffs, ash flow tuffs, and tuff breccias. Pliocene rocks contain moderately welded to densely welded tuffs with overlying basalt rhyolite flows. Quaternary sediments are chiefly alluvial and fluvial fanglomerates, interbedded with mud flows and lake deposits.

HYDROGEOLOGICAL SETTING

The NTS lies in the most arid region of the U.S., thus any surface water exists as ephemeral streams, however during periods of extended precipitation, runoff does collect in Yucca and Frenchman playas forming shallow, temporary lakes. Groundwater hydrology on the NTS is complex and is best discussed in the following sections: the grouping of geologic formations in aquifers and aquitards; the distribution and saturation extent of the aquifers; and groundwater movement.

Ten hydrogeologic units were designated from the geologic formations present in the area from well data. By order of decreasing age they include the following (Table 1): lower clastic aquitard; lower carbonate aquifer; upper clastic aquitard; upper carbonate aquifer; tuff aquitard; lava flow aquitard; bedded tuff aquifer; welded tuff aquifer; lava flow aquifer; and the valley fill aquifer. The lower clastic aquitard is widely distributed throughout the NTS, is the hydraulic basement for carbonate rocks in the region, and perhaps controls the regional groundwater movement. The lower carbonate aquifer overlies the lower clastic aquitard and groundwater movement through it is controlled primarily by fractures and subsequent solution enlargement. Major eastern Nevada springs are fed through this aquifer and it is the only source of potable water on the NTS where the valley fill aquifer is unsaturated. The upper clastic aquitard is hydrogeologically significant as it separates the upper and lower carbonate aquifers hydraulically and stratigraphically. The upper carbonate aquifer consists of Pennsylvanian limestone and is absent from most of the study area with exception to western Yucca Flat where it is saturated at depths below 600 m. Regional groundwater movement is not affected or controlled by the upper carbonate aquifer because of its limited areal and saturated extent. The tuff aquitard separates the Paleozoic and Cenozoic aquifers in Frenchman, Yucca, and Jackass Flats. Poor interstitial permeability and hydraulic connection of fractures probably accounts for the aquitard's ability to control regional groundwater movement. Most nuclear devices are tested in tuffs above the carbonate aquifers because of its poor hydraulic conductivity, great thickness and wide areal extent. Little is known about the lava flow aquitard because few drill holes have penetrated it. Occurrence of the lava flow aquitard is limited primarily to the northwest section of Frenchman Flat. The bedded tuff, welded tuff, and lava flow aquifers are widely distributed throughout the NTS, however saturation is limited to structurally deep portions of Frenchman, Yucca and Jackass Flats.

Depressions created by post-Pliocene block faulting and subsequent erosion of ridges producing alluvial-colluvial fans, mud flows and lake bed deposits is the valley fill. Valley fill deposits consist of brown to tan to gray, tuffaceous silts, sands, and gravels moderately cemented with calcium carbonate. Hard caliche layers are common in Jackass, Frenchman, and Yucca Flats alluvial fan sediments at approximately one meter and is a common cementing material throughout the valley fill sediments. Lake bed deposits are chiefly illite, mixed-layered clay minerals, and montmorillonite, thinly laminated at the surface and becoming more massive with depth (Moore and Garber 1962). Thickness of the valley fill is 570 m. beneath central Yucca Flat, 370 m. beneath central Frenchman Flat and 320 m. beneath central Jackass Flats. The valley fill is the major aquifer used for water supply in Frenchman Flat and is saturated locally in structural lows of Yucca and Jackass Flats. Pump tests of the valley fill aquifer yields transmissibility values ranging from 10 to 420 $m^3/d/m$.

Distribution and saturated thicknesses of the hydrogeologic units discussed are highly variable both laterally and vertically in the subsurface due to Tertiary block faulting and pre-Tertiary folding, faulting, and erosion. The lower carbonate aquifer is generally saturated throughout the area. It is confined in structurally deep parts of basins and unconfined beneath ridges. The tuff aquitard separates the welded tuff aquifer and valley fill aquifers from the lower carbonate aquifer in structurally deep portions of Frenchman, Yucca, and Jackass Flats. In buried pre-Tertiary structural highs the Cenozoic aquifer may be in direct contact with the lower carbonate aquifer; and water table depth is not an important factor for determining extent of saturation of the lower carbonate aquifers due to great thicknesses of the upper and lower clastic aquitards.

Three types of groundwater movement occur in the NTS; movement of perched water, intrabasin movement, and interbasin movement of water. Perched water or water separated from an underlying body of groundwater by unsaturated rock occurs in ridges and foothills of Frenchman and Yucca Flats in lava flows and tuff aquitards. Nine perched springs have been observed in the area. Intrabasin movement of water is downward movement or drainage of water from the Quaternary valley fill aquifer to Paleozoic carbonate aquifers. Evidence of this kind of movement was obtained via test drilling in Yucca Flat (Moore 1963). Interbasin movement of water is water which moves laterally beneath basin floors and surrounding ridges. Water levels in wells penetrating the lower carbonate aquifer indicate a hydraulic gradient from northwest Yucca and eastern Frenchman Flat toward Ash Meadows and the Amargosa desert ranging from 0.06 to 1.10 m./km. towards the southwest. Groundwater movement toward the Ash Meadows discharge area is controlled by major strike slip, normal, and thrust faults. It is suggested that the NTS is hydraulically connected through interbasin movement to at least ten intermontane valleys and receives significant amounts of underflow from northeastern basins (Mifflin, 1968, and Winograd and Thordarson, 1975).

ROADLOG

DAY 1

Nevada Test Site

Mileage

0.0 Department of Energy Building. Las Vegas, NV. The trip begins from the parking lot and proceeds north to the Nevada Test Site. Exact directions are not given since this trip cannot be duplicated without the permission of the Department of Energy (DOE).

27.6 STOP 1. NORTHWEST LAS VEGAS VALLEY BADLANDS

Exposed intermittently from southeast of the Tule Springs area, about 13 km. to the north of Las Vegas, to within 13 km. of the Mercury turnoff (a total of about 67 km.) are light colored fine-grain sediments of Quaternary age. These contrast sharply with the coarse alluvial fan gravels presently being deposited. In some areas, such as around and immediately north of Tule Springs, the combination of incision by Las Vegas Wash (developed along the axial part of the valley) and alluvial fan tributary washes has created badland topography on the light colored sediments. On casual examination some of these deposits appear to be lacustrine and were attributed to pluvial "Lake Las Vegas" by early investigators. However, as pointed out by Mifflin and Wheat (1979), paleoclimate models based on the distribution of well-documented pluvial lakes in the Great Basin strongly argue against such a large, exclusive lake in Las Vegas and Indian Springs Valleys, and absence of basin closure and shorelines add additional weight to another mode of origin. The evidence to date points to periods of active and extensive ground-water discharge associated with the past pluvial climates. These sediments have been studied by Haynes (1967) and Quade (1982) in great detail in several areas of their extent. The majority of exposed fine-grained sediments range in age from greater than 30,000 yrs. B.P. to about less than 5,000 yrs. B.P., with C-14 dates, fossil assemblages, facies changes, and paleosols being used to establish the general age and stratigraphic relationships. Depositional environments indicative of spring discharge, wet meadows, marshes and perennial stream flow are indicated by sedimentary features and fossil assemblages incorporated within various units and facies of the deposits. Wet periods are interpreted as times of extensive ground-water discharge, and other units indicate dry periods with markedly reduced discharge of ground water, perhaps similar to current conditions of ground-water discharge i.e., only a few isolated spring areas: Tule Springs, Corn Creek Springs, and Indian Spring/Cactus Springs. Evidence has been noted by Quade (1982) for secondary calcite related to former water-table positions (the calcareous zones cut across stratigraphic horizons when traced from axial valley exposures to more valley marginal exposures). Fossil assemblages include large mammals, mollusks, and in some horizons, abundant casts of cicada burrows.

The stratigraphic sequence, initially described by Hayes (1967) in the Tule Springs area, extends to the fine-grained deposits to the north, around Corn Creek Flat and the Indian Springs area, studied in detail by Quade (1982). Quade combines and summarizes the findings as follows: Units A and B are only exposed in the lower valley in the vicinity of the Tule Spring, the oldest exposed archaeological site. Haynes correlates at least the upper part of Unit B to the Altonian Substage of the midwestern glacial sequence. Unit B contains greenish pond clays, black mats, and cicada burrows indicative of moist conditions. Overlying Unit C represents a shift to dryer conditions prior to the onset of Late Wisconsin pleniglacial conditions. All these units fall beyond the range of carbon-14 dating.

Unit D contains a suite of different facies interpreted to represent an extensive marsh-lake complex deposited within the time interval of 30,000 yrs. B.P. to roughly 16,000 yrs. B.P. On Corn Creek Flat during this time, a broad alluvial sand flat surrounded shallow marshy or wet meadow areas in the valley center. Around the Tule Spring archaeological site, a more continuous body of shallow water was surrounded by a similar alluvial flat. Abundant secondary carbonate found in beds of Unit D and earlier, was at least part precipitated off of a capillary fringe. Unit D probably correlates with Early and Mid-Pleniglacial (25,000 to 15,000 yrs. B.P.) deposits of Pluvial Lakes Lahontan and Bonneville.

Unit E is younger than Unit D and also consists of facies indicative of perennial water at or near evidence for gradual shrinkage of the marsh-lake complex during the period 13,500 to 7,200 yrs. B.P. This change may have been entirely due to changing climatic conditions or in the case of Unit E, possibly it resulted from disruption of basin closure shortly before E_1 deposition. Standing bodies of water persisted in the Corn Creek area through Unit E_1 time, and they were connected to Tule Springs Flat by a marsh-fringed perennial stream occasioned by horse, camel, mammoth, and other megafauna. Unit E_2 records persistence of moist conditions to 7,200 yrs. ago in the form of black mats, mollusk-rich fluvial deposits, and abundant burrowing by cicadas. Megafauna were probably present in the area into early Unit E_2 time (11,200 - 7,200 yrs. B.P.) when the earliest presence of paleoindians is also recorded.

Unbioturbated eolian and fluvial deposits testify to the xeric depositional conditions under which Units F and G were formed after about 6,500 yrs. B.P. Limited dissection of fringing areas probably began during Unit E_2 depositon, whereas widespread dissection of fine-grained deposits began after 7,000 yrs. ago. An increase of exotic volcanic detritus (from the northwestward volcanic terrane of the NTS area?) in mid-Holocene sediments and younger argues for a greater role of eolian processes in sediment transport during the shift to a dryer and/or warmer climate.

42.8 Indian Springs -- A small community and Air Force Base named after a perennial spring with a discharge of approximately 0.04 m^3/s.

44.2 Cactus Spring.

64.0 Gate to the Nevada Test Site -- Mercury, Nevada

68.0 View of Frenchman Flat.

Traveling north of Mercury, an exposure of Paleozoic carbonate rock can be seen in Red Mountain to the west and the Mercury Ridge to the east. These Cambrian to Devonian age rocks represent the southern extent of the Cordilleran Miogeosyncline. The Range Mountains and the Buried Hills east and northeast of Frenchman Flat are also Paleozoic exposure. The Rock Valley fault zone crosses the road south of Frenchman Lake. This fault zone is a left lateral component of the major right lateral, northeast trending component of the major right lateral, northeast trending Walker Lake-Las Vegas Shear zone. The Cane Spring fault, northwest of Frenchman Flat is a similarly associated left-lateral fault system. North and west of the playa are the Massachusetts Mountains and Mt. Salyer respectively. These mountains consist of Tertiary volcanic rocks, most of which are ash flow or ash fall tuffs. The broad, gently sloping basin is underlain by about 400 m. of alluvial and colluvial fill derived from the bordering mountains.

75.7 STOP 2. RADIONUCLIDE MIGRATION PROGRAM (RNM Ditch).
This program has been a cooperative effort between the DRI, LANL, LLNL, USGS.

The Radionuclide Migration Program (RNM) is a study of the factors that control movement both on and off the Nevada Test Site of radioactivity from underground nuclear explosions. This information is applicable to the hydrologic studies related to long-term safety with regard to contamination of water supplies both on- and off-site.

The RNM Program consists of various tasks including experiments at specific sites on the NTS, laboratory work related to the field experiments, and mathematical modeling of the field and laboratory results. The most intensive investigation is currently in progress at the site of the Cambric event.

Cambric was chosen for a number of reasons: 1) the Cambric explosion cavity is within the NTS Area 5 water-supply aquifer, and there was particular interest in possible contamination of water supplies; 2) it was predicted that sufficient time had elapsed so that the cavity and chimney had filled with ground water to the preshot static water level, 73 m. above the detonation point. If so, radionuclides might be present in the water and constitute a potential source for migration; 3) the Cambric detonation point is only 294 m. below ground surface, and thus the reentry drilling and sampling operations would be less difficult and expensive than for more deeply buried tests. The site in Frenchman Flat is far enough from the areas of active nuclear testing so that damage or interruption of the reentry and sampling operations from those activities would be unlikely; 4) sufficient tritium (^3H or T) was present to provide an easily measurable tracer for water from the cavity region; 5) the postshot debris also contained plutonium, uranium, and fission products whose concentrations in the rubble and ground water from the cavity and chimney regions could be measured and compared; 6) the small yield (0.75 kt.) was expected to have had little effect on the local hydrology; 7) 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 information from Cambric has contributed significantly to the understanding of the radionuclide mobilization and transport mechanism in the NTS ground-water environment.

In 1974, two holes were drilled for radionuclide migration studies at the site of the Cambric test. The Cambric cavity region was reentered, and a hole (RNM-1) was completed to a depth of 370 m. Samples were taken to determine the radionuclide distribution between the solid material and water at the time the experiment was started. Water was then pumped from a nearby satellite well (RNM-2s, actually drilled before RNM-1 to avoid contamination), so as to induce an artificial gradient sufficient to draw water from the Cambric cavity and provide an opportunity for the study of radionuclide migration under field conditions. The pumped water was discharged to a ditch and conducted to a pond on Frenchman Flat where it is permitted to evaporate and infiltrate.

Three types of samples were removed from the RNM-1 reentry hole into the Cambric cavity: side cores, pumped water, and water with contained gases. Solid samples and water removed from the side wall cores from the lower cavity region were analyzed radiochemically for ^{90}Sr, ^{137}Cs, and ^{239}Pu, and effective distribution coefficients (ratio of the concentration in or on the solid to the concentration in the aqueous phase) were determined. These effective distribution coefficients are a measure of both retention in the fused material and sorption. The radionuclides were found to be almost entirely incorporated in or on the solid material.

After sidewall core sampling had been completed and the hole had been cleaned, casing was installed. Beginning at the bottom, the water in five zones was sampled successively by isolating the zones with internal packers and perforating the casing.

Ten years after the test most of the radioactivity and the highest concentrations of all radionuclides were still found in the region of the original explosion cavity. No activity was found 50 m. below the cavity. The measured ^{85}Kr to T ratios for water from the explosion cavity zone were consistent with the relative amounts resulting from the Cambric test. No krypton was observed in water or solid material from cores taken above the water table. Water from the region of highest radio-activity at the bottom of the cavity contained only tritium and ^{90}Sr at levels higher than the recommended concentration guides for effluent water in uncontrolled areas.

By comparing the measured ratio of each nuclide detected in the water to the tritum in the water with the calculated ratio of the same nuclide to tritum for the Cambric test, an effective overall retention factor, E_d, for each nuclide (ratio of the total activity in or on solid to the total activity in the aqueous phase) was estimated. The nuclides ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{137}Cs, and ^{239}Pu were all found to have high retention factors, indicating they are either retained in the fused debris or highly sorbed on the solid material, or both.

After completion of the initial studies described above, the packer between the two uppermost zones was drilled out and the pump was left in place to sample the water. Since pumping started at the satellite well, periodic sampling has been performed to determine remaining levels of radioactivity. For example, in 1982 after 6.5 yrs. of pumping at RNM-2s (6.5 X 10^6 m^3 of water), the tritium concentration in water pumped from RNM-1 had decreased nearly 2,000-fold. Concentration of ^{85}Kr, ^{90}Sr, and ^{137}Cs have also been measured and had decreased (Daniels, 1981).

The satellite well RNM-2s is located 91 m. from the Cambric explosion cavity. Pumping was begun in October 1975 at a rate of about 1 m^3/min; in October 1977, the rate was increased to about 2.3 m^3/-min. Significant amounts of tritiated water, signaling arrival of water from the Cambric cavity region, were finally detected after about 1.44 x 10^6 m^3 of water had been pumped from the satellite well. After seven yrs. of pumping, the tritium concentration in the pumped water reached a maximum of nearly 3 nCi/ml (the maximum permissible concentration for drinking water in a controlled area such as the NTS) and is now decreasing. Removal of 7.1 x 10^6 m^3 of water from RNM-2s by early October 1982 has also removed 42 percent of the tritium available from Cambric.

Large volume water samples (0.21 to 0.90 m^3), taken at intervals from RNM-2s since the first observation of tritium, were reduced to solid residues by evaporation, and the gamma-ray spectra observed. With the exception of a very small amount of ^{106}Ru (concentration < 1 percent of that produced in Cambric), no gamma-emitting nuclides have been identified in these samples. Radiochemical analyses of other water samples for the beta-emitting nuclide ^{90}Sr also gave negative results.

Chlorine-36 produced by the Cambric event has been detected in water samples from RNM-2s using accelerator-based mass spectrometry. The breakthrough of ^{36}Cl appears to arrive earlier than that of tritium, and the peak in the chloride elution clearly occurs before tritium. This phenomenon, (called anion exclusion) where anions arrive earlier than cations or neutral species in packed columns, has been observed in soil chemistry studies and column chromatography.

Iodine-129 has been observed in water pumped from RNM-2s. Although the concentrations are well below the maximum permissible concentration of 6 x 10^{-5} nCi/ml for drinking water in a controlled area, mobile radionuclide species of any kind are of interest to the general understanding of radionuclide transport.

Relative to the ^{129}I concentrations measured in RNM1 (1.1 x 10^{-5} nCi/ml), only about one quarter as much ^{129}I compared to tritim has been recovered at RNM-2s.

A DC earth resistivity study along the RNM ditch was conducted in the hopes that relative distributions of soil moisture could be distinguished. A series of vertical soundings were completed at 3, 15, 25, 30, and 45 m. away from the ditch and on both sides of the ditch in order to provide a two-dimensional, cross-sectional view of resistivity. These data have been converted from apparent resistivity versus electrode spacing to true resistivity versus depth and have been contoured on the basis of electrical conductivity. Two holes have been drilled for soil moisture samples near the ditch for comparison with the resistivity data.

A three-dimensional hydraulic and solute transport numerical modeling study has been recently completed. The goal of this study was to formulate a conceptual model of the RNM site and incorporate it into a three dimensional solute transport model in order to monitor the migration of tritium and chloride-36 through the geologic system and to predict the time necessary to extract all the tritium from the system.

Hydrologic data from a nearby well was used and correlated with that of RNM-1. Analysis indicates that playa type sediments dominated the depositional scheme at depths of 285-330 m. below the present land surface. Hydrologic parameters such as hydraulic conductivity and porosity were estimated from these correlations. Dispersivity values were estimated from analytic solutions. The tritium source term and the tritium exchange radius were determined statistically using a T-test at a 95% confidence level.

The model selected for this study was titled the Deep Well Disposal Model. It was selected for its versatility of use and its incorporation of the third dimension. Symmetry of the radially converging flow field was applied by using 1/4 of the total cylinder of pumping. This scheme allowed for considerable savings in computer memory and execution time.

The hydraulic conductivity and porosity of the cavity region were estimated using trial and error tests. Once the hydrologic scenario was established, it was necessary to incorporate a retardation or retention factor to get the simulated breakthrough data to fit the field data. Various possibilities for the delay included adsorption of tritium, exchange of tritium with structural water, and self diffusion of tritium into zones of immobile water between pores.

Predictions as to the time needed to pump out the tritium mass were determined. Breakthrough curve data didn't represent the peak concentration within the system at that particular time. Contour plots showed that significant tritium remained in the system well after RNM-2s readings showed little or no tritium remaining.

Chloride-36 data was analyzed for two reasons. First, its breakthrough time and time to peak occurred earlier than that of tritium. Results indicated that anion exclusion might have been the major reason for the time difference. Secondly, by using the same hydrologic data used for tritium, but lowering the retardation factor and reducing the size of the source term, simulated results showed excellent agreement with the field data. This indicated that the conceptual model used closely approximates that of the "real world".

Although it may be disturbing to find that tritium will remain in the system in lower conductivity layers for more than 22 years after the initiation of pumping, which is much longer than RNM-2s breakthrough curve data indicates, evidence indicates that there is little danger of fission products migrating any significant distance away from nuclear-produced cavities.

One major question still remaining which will be attempted to be answered through the ongoing RNM research is whether tritium is actually being delayed by adsorption, or ion exchange processes, or whether its delay can be explained by self diffusion into immobile water regions. It will also be beneficial to determine whether chloride-36 is experiencing accelerated movement through the system due to anion exclusion or whether it too is actually being delayed by the self diffusion process to some degree.

Of moderate concern is the possibility that tritium may be reentering the system through a drainage ditch which is used to carry pumped water away from the RNM site. If tritium is being recycled, it would be interesting to determine how the breakthrough curve would be affected if at all.

Overall, there is still much continued work that needs to be done. This project has answered many questions on the migration of tracers, but an equal amount have arisen in conjunction with the findings in this study. In many instances, average values were used; especially in and around the cavity region where there was limited data available. However, strong agreement of simulated data to field data indicates that average values within the cavity region are adequate for predictive modeling purposes. Additional information is not needed to accurately simulate the field situation. The work in this study does offer insight into the long range picture dealing with radionuclide transport and the risks involved in underground nuclear testing.

78.7 STOP 3. RADIOACTIVE WASTE MANAGEMENT SITE.

The third stop is the transport study site in Area 5 (Fig. 2). The site is adjacent to the Radioactive Waste Management Site (RWMS) and provides a field laboratory where data may be collected which quantitatively describe the physical processes controlling moisture movement in the upper 6 m. of the unsaturated zone. The unsaturated flow characteristics of the soil in and around the RWMS are being delineated in order to estimate the rate of movement, should movement occur, and hence the possible time of arrival of radionuclides traveling from the RWMS to the water table and possibly to the biosphere.

The relevant unsaturated flow characteristics are the pore-volume frequency distribution, pore-radius frequency distribution, porosity, chemical interactions between impurities in the water and the soil-capillary walls, degree of saturation, and the ambient temperature as well as the variations in these parameters with position and time as characterized in summary form by the matric potential of the water (ψ) in the soil. The negative gradient of the matric potential is the driving force for the movement of water in the vadose zone.

These parameters are related to the flow velocities in the following way. From matric potential data it is possible to compute gradients of matric potential as a function of position and time. A curve fitting technique described by Van Genuchten (1978) was used to calculate a curve of unsaturated hydraulic conductivity ($K(\theta s)$) as a function of degree of saturation (θs). Information used to generate this curve are volumetric moisture content, a site specific moisture characteristic curve, and the saturated hydraulic conductivity of the soil. From the degree of saturation data, it is possible, using this curve, to generate unsaturated hydraulic conductivity values as a function of position and time. The hydraulic conductivities combined with the gradients of matric potential allow computation of volume flux (J), volume per area per unit time, or Darcy velocity, i.e.

$$\vec{J} = -\vec{K}(\theta_s) \circ \vec{\nabla} h$$

where h is the head or matric potential divided by the product of the density of the fluid in the porous medium times the acceleration due to gravity. (Sample results are shown in Fig. 3 and are discussed below). The actual water velocity in the pores, or pore velocity (V_p) is the Darcy velocity divided by the average porosity (ε), of the medium.

The chemistry of the soil water and soil mineralogy determine what nuclide species will be soluble such as uranium in a carbonate environment--and which will be insoluble--such as uranium in a high sulfate environment. The cation exchange and sorption characteristics of the soil determine whether the moisture movement in the unsaturated zone may be inhibited or enhanced, directly affecting the rate of radionuclide transport.

Three independent studies to date have been conducted at the transport study site. They include: a simulated 500 year precipitation event and construction of a soil moisture characteristic curve for the RWMS (Kearl, 1982); describing the soil mineralogy and chemistry with an emphasis on sorption properties of cesium (Cs^+) and strontium (Sr^{2+}) (Kautsky, 1984); and determining the spatial variability of unsaturated hydraulic conductivity in the near surface (Panian, work in progress).

To measure temperature and water potential, thermocouple psychrometers were buried at various depths on the study plot. The psychrometer probes contain a copperchromel thermocouple for measuring the matric potential (ψ) in the soil and a copper-constantan thermocouple to measure temperature. The psychrometers were connected to a central instrument shed containing a psychrometer scanner used to automatically record and measure these parameters. A neutron moisture probe was used to measure moisture content in the study area. Eight aluminum access tubes were installed to a depth of about 6 m. A neutron moisture gauge containing an americium-241 beryllium source was lowered into the tubes and measured moisture content with depth.

The saturated hydraulic conductivity was measured in the field with a flooding single ring infiltrometer and in the laboratory from undisturbed soil cores taken from the study area.

The porosity of the soil was estimated from comparison of the grain size distribution of the soil at the study site to soils of known porosity discussed in the literature.

Representative soil samples were collected at the site in order to characterize the soil and its adsorption properties with respect to Cs^{+} and Sr^{2+}. Samples were collected using a hand auger and a trailer-mounted hollow stem auger at depths ranging from 2 to 9 m.

Chemical analyses thus far have consisted of estimates of cation exchange capacity, soluble salts, exchangeable sodium percentage, pH, and electrical conductance. Textural analyses were conducted by the hydrometer method and the clay fraction was X-rayed in order to identify minerals whose ion adsorption characteristics may be unique.

From the curve of unsaturated hydraulic conductivity for near-surface soil near the study site as a function of degree of saturation, along with the other parameters described above, a volume flux (J) and a pore velocity (Vp) were computed for the study site. A typical value of pore velocity for the conditions of saturation found to date is 10^{-8} cm/sec or about 1/3 of a cm/yr. Example results of volume flux as a function of time are shown for two depths at one location in Fig. 3. It is seen that near land surface moisture flows toward land surface for most of the year except for the winter months when the

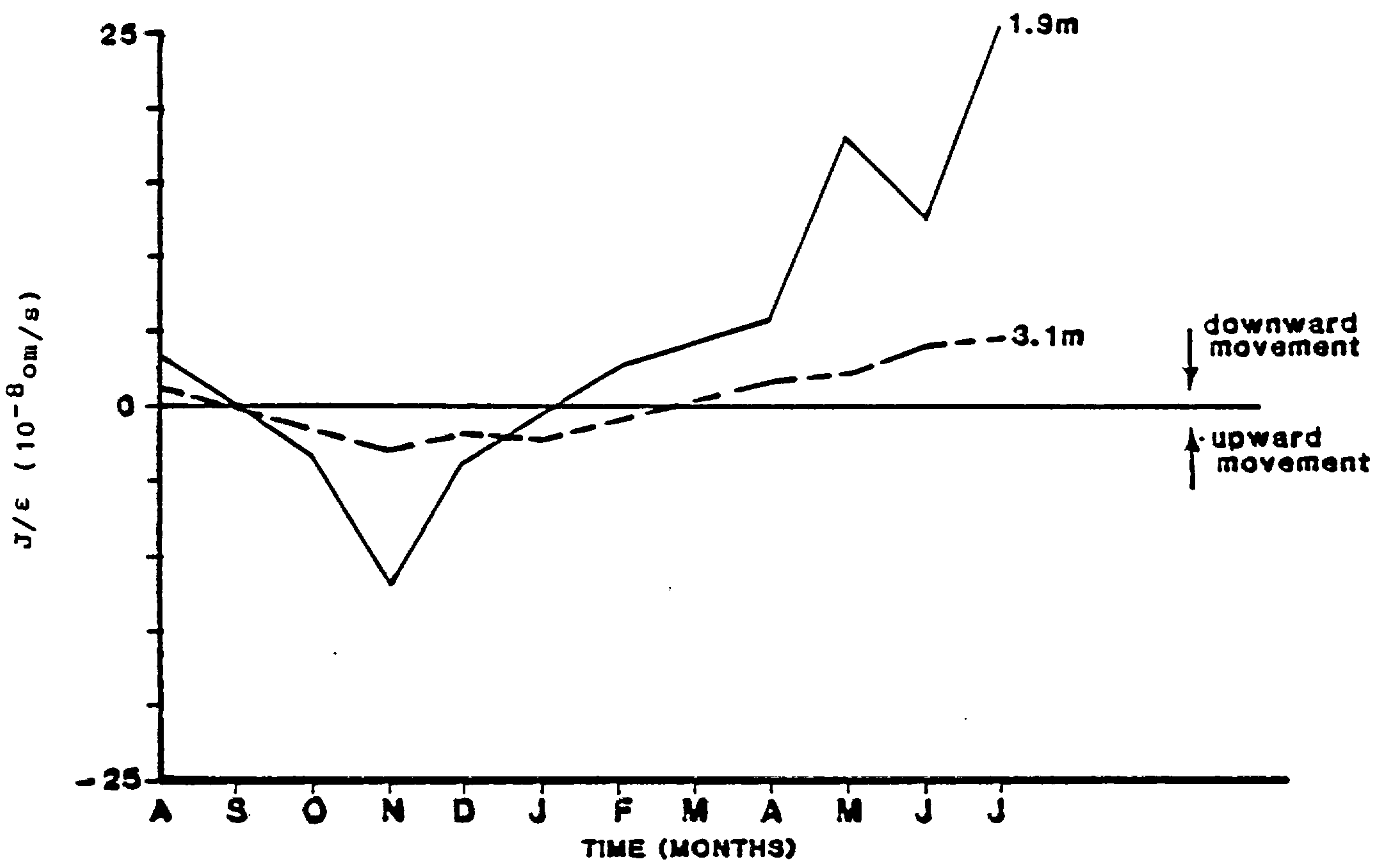

FIGURE 3 Unsaturated groundwater flow velocity as a function of time at two respresentative depths.

trend is downward.

FLOOD HAZARD EVALUATION

Hydrologic analyses in general and flood hazard evaluations in particular are difficult to perform in desert and arid regions. In such areas stream gaging records are usually of short length, when they exist, and are usually composed of many low outliers with only a few meaningful values. With these data limitations, the traditional methods of peak flood flow estimation are not applicable and regional peak flood flow regression equations or rainfall runoff models are frequently used.

Another difficulty in evaluating potential flood hazards to facilities in arid regions occurs when the facility is sited on one or more alluvial fans. From a quantitative viewpoint, the formation of these important geological features and the movement of flood flows across them are very poorly understood.

The Radioactive Waste Management Site (RWMS) is located at the junction of major alluvial fans to the east and west, with several smaller fans merging from the north; Fig. 4. The conclusion is that the RWMS is likely to be hit several times during an assumed design life of 100 yrs. by flash flood events of significant magnitude. This conclusion was arrived at by using regional peak flood flow equations developed by the U.S. Geological Survey and various hypotheses regarding flood processes on alluvial fans.

Although this analysis is subject to a number of serious limitations, the conclusion was substantiated by the fact that the RWMS is located on a number of alluvial fans which were formed by erosional processes that are still active.

83.1 Going up the alluvial fan to your left is the road to Jackass Flat, Fortymile Canyon and Yucca Mountain. Ten km. up this fan is Cane Spring, the site of investigations of the behavior of a shallow perched groundwater system.

Time-series data have been collected over the past 4 yrs. The parameters measured were discharge, gross chemistry and environmental isotopes. These data are used to analyze recharge to shallow ground water in a semi-arid environment. This is used to resolve travel times and flow velocities in a fractured medium (Jacobson and Hess, 1984). It appears that the residence time for some of the discharging water in the unsaturated zone is approximately one month and approximately six months in the saturated zone.

Cane Spring is located at 36°47'56" N. Lat., 116°05'42" W. Long. at an elevation of 1238 m. on the northeast trending Cane Spring Fault Zone. The spring lies low on a hillside about 0.9 km. south from a southward bend in Cane Spring Road at a point roughly 10 km. west from its juncture with Mercury Highway.

Soils in the area are poorly developed in alluvial materials, which derive from the surrounding high ground composed of Miocene aged volcanics of the Wahmonie and Salyer Formations (Poole, Elston, and Carr 1965). The Wahmonie in the spring vicinity is primarily composed of dacite and rhyodacite lava flows containing quartz, plagioclase feldspars, pyroxene, hornblende, biotite, and magnetite. The Salyer here is composed of lithic breccias, breccia flows, tuffs and tuff breccias, and sandstones of similar mineralogy. The bedrock in the area is highly fractured and faulted, with numerous smaller faults terminating in the Cane Spring Fault Zone, mostly from the south.

Water at the spring collects in an adit, hand dug roughly 15 m. southward into the hillside at a shallow angle. The adit pool contains an estimated 21 cu. m. of water. The water, audibly trickling into the pool near the back, currently discharges through a gravity-feed pipe under a small earthen dam at the mouth of the adit. However, large trees and wet soils (the latter observed in July of 1980), some 50 m. from the adit at the same elevation, indicate local groundwater discharges other than that represented by the adit pool.

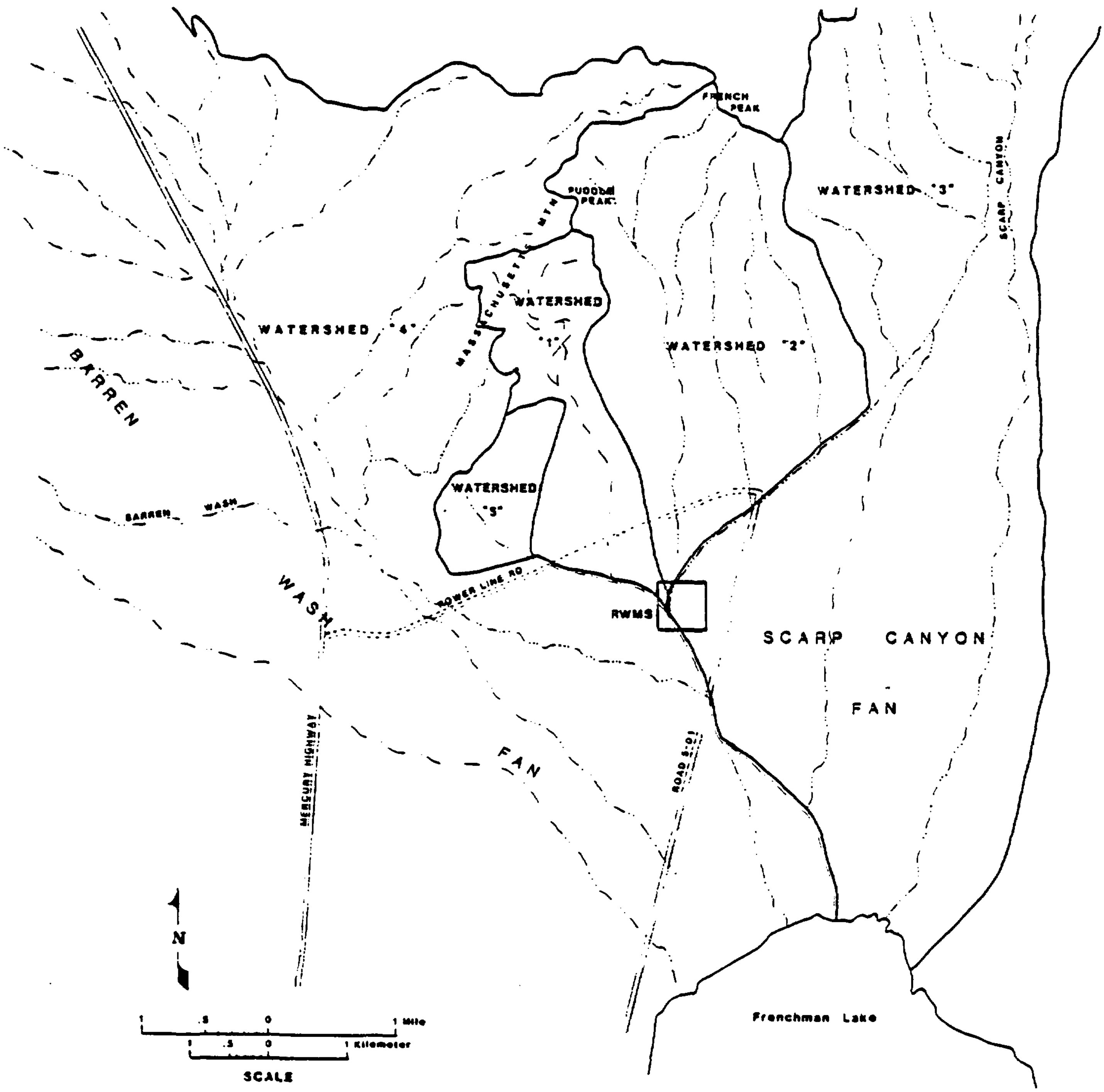

FIGURE 4 Location of RWMS relative to the surrounding alluvial fans

100.0 Intersection of Tippipah Highway and Pahute Mesa Roads. To the west of this intersection is the site of the wash infiltration study.

WATER MOVEMENT IN DESERT DRY WASHES

Recent isotopic and water chemistry studies indicate that groundwater recharge in arid zones occurs via ephemeral wash channels after flood events. This study assesses such recharge potential by examining the soil-water-climate-vegetation interactions in the upper 9 m. of a wash channel, as the primary water infiltration restraints of evaporation and transpiration by vegetation are most intense in this region.

Based on the geomorphic and geologic characteristics of the wash and its drainage basin, and the availability of past precipitation, psychrometer and electrical resistivity survey data, of a particularly flood prone wash above the NTS Area 1 Shaker Plant was chosen. The study site elevation is about 1525 m. and the average annual precipitation is 20 cm. After doing a shallow seismic survey so as to avoid caliche underlain areas, 9 m. holes were drilled in a well-defined alluvial channel and an interchannel area (as a control), each instrumented with 2 psychrometers (which measure temperature and soil water potential) and a soil gas collection port (to collect soil water vapor) at 0.5, 1.0, 2.6, 4.2, 5.8, 7.4, and 9.0 m. Aluminum cased neutron probe access holes were installed adjacent to each of these to allow determination of water content. To collect water samples independent of the gas collection ports, suction lysimeters were installed at 0.5 and 1 m. depths. Fig. 5 is a cross-section showing instrumentation in the wash site.

A soil moisture potential, water content, and temperature profile of all of the holes is made weekly. Soil water and vegetation samples have been collected monthly and analyzed for oxygen and hydrogen isotope ratios. Through comparison with collected precipitation and runoff, a calculation of the evaporative processes acting on the water during infiltration has been made, and the horizons that several sizes and species of plants utilize as water sources identified. Combined, the resulting data will indicate the net direction, magnitude, and character of water movement in this micro-environment through time, thus establishing a baseline for further studies of ephemeral wash recharge on a larger scale.

105.4 To the right, down the alluvial fan is hydrologic test well Ue2ce.

109.5 STOP 4. AREA 12 CAMP -- Lunch.

111.6 View of Rainier Mesa and Tunnel Portals.

113.0 STOP 5. VIEW OF RAINIER MESA AND YUCCA VALLEY.

The tunnels into the tuffs of Rainier Mesa afford a unique opportunity to intercept unsaturated flow halfway down to the water table. This allows investigations of recharge mechanisms and the movement of water through thick unsaturated zones. Precipitation amounts, chemistry and isotopic composition are measured on the top of the mesa at several points. Additionally, soil moisture contents and chemistry are also determined. These data are then compared to discharge, water quality and isotopic composition of tunnel waters. This allows the calculation of residence times and probable flow paths.

The geology of Rainier Mesa affects both the groundwater flow and the geochemical reactions that occur within the tuffs. Minerals found in the various strata of the mesa show those constituents which might be at saturation level within the groundwater. The groundwater flow and mineral precipitation govern the chemistry of waters collected from the tuffs of the mesa.

As seen from Yucca Flat, Rainier Mesa is composed of a succession of nearly parallel stratigraphic units with a slight dip of 10 to 25° to the west. Thicknesses of these strata vary considerably, dependent upon location. Measurements have been made in numerous drill holes, in tunnels penetrating the mesa, and in

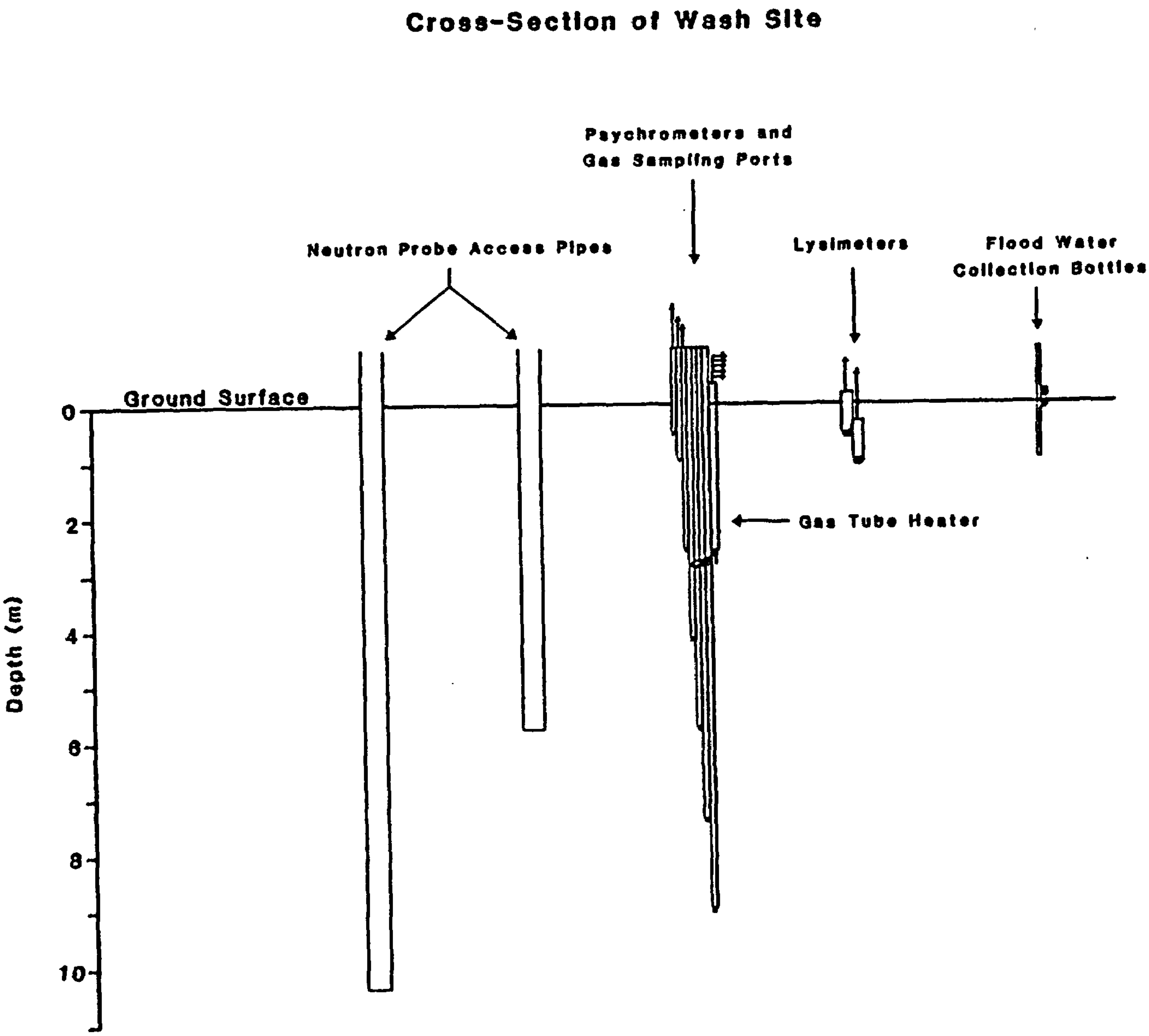

FIGURE 5 Instrumentation schematic of the Wash Site

exposed areas on the sides of the mesa. A compilation of these data is given in Table 1.

Faulting and fracturing of the volcanic tuffs are found in many locations throughout Rainier Mesa; at times these faults extend only through one or several stratigraphic units. Many of the faults visible on the surface of the mesa are indicated on the map by Gibbons et al., (1963). The surface is extensively scarred by erosional gullies controlled by cooling fractures, joints, or small faults (Fairer et al. 1979). The mesa has been modified in one location by a series of broad shallow anticlines and synclines (Hansen, et al., 1963).

Abundant fractures in Rainier Mesa are most visible in the welded and partially welded tuffs, where they were created by cooling as well as structural deformations. Fractures are also present in the zeolitized tuffs, although to a lesser extent. The friable nature of the vitric-

TABLE 1. Stratigraphic and hydrogeologic units at Nevada Test Site and vicinity (After Winograd and Thordarson, 1975)

System	Series	Stratigraphic unit	Major lithology	Maximum thickness (feet)	Hydrogeologic unit	Water-bearing characteristics and extent of saturation [1]
Quaternary and Tertiary	Holocene, Pleistocene, and Pliocene	Valley fill	Alluvial fan, fluvial, fanglomerate, lakebed, and mudflow deposits	2,000	Valley-fill aquifer	Coefficient of transmissibility ranges from 1,000 to 35,000 gpd per ft; average coefficient of interstitial permeability ranges from 5 to 70 gpd per sq ft; saturated only beneath structurally deepest parts of Yucca Flat and Frenchman Flat.
Tertiary	Pliocene	Basalt of Kiwi Mesa	Basalt flows, dense and vesicular.	250	Lava-flow aquifer	Water movement controlled by primary (cooling) and secondary fractures and possibly by rubble between flows; intercrystalline porosity and permeability negligible; estimated coefficient of transmissibility ranges from 500 to 10,000 gpd per ft; saturated only beneath east-central Jackass Flats.
		Rhyolite of Shoshone Mountain	Rhyolite flows.	2,000		
		Basalt of Skull Mountain	Basalt flows.	250		
		Piapi Canyon Group, Timber Mountain Tuff: Ammonia Tanks Member	Ash-flow tuff, moderately to densely welded; thin ash-fall tuff at base.	250	Welded-tuff aquifer	Water movement controlled by primary (cooling) and secondary joints in densely welded part of ash-flow tuff; coefficient of transmissibility ranges from 100 to 100,000 gpd per ft; intercrystalline porosity and permeability negligible; unwelded part of ash-flow tuff, where present, has relatively high interstitial porosity (35–50 percent) and modest permeability (2 gpd per sq ft) and may act as leaky aquitard; saturated only beneath structurally deepest parts of Yucca, Frenchman, and Jackass Flats.
		Piapi Canyon Group, Timber Mountain Tuff: Rainier Mesa Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff at base.	600		
	Miocene	Piapi Canyon Group, Paintbrush Tuff: Tiva Canyon Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff near base.	300–350		
		Piapi Canyon Group, Paintbrush Tuff: Topopah Spring Member	Ash-flow tuff, nonwelded to densely welded; thin ash-fall tuff near base.	890		
		Piapi Canyon Group, Paintbrush Tuff: Bedded tuff (informal unit)	Ash-fall tuff and fluvially reworked tuff.	1,000	Bedded-tuff aquifer	Coefficient of transmissibility ranges from 200 to 1,000 gpd per ft; saturated only beneath structurally deepest parts of Yucca Flat, Frenchman Flat, and Jackass Flats; Occurs locally below ash-flow tuff members of Paintbrush Tuff and below Grouse Canyon Member of Indian Trail Formation.
		Wahmonie Formation	Lava-flow and interflow tuff and breccia; locally hydrothermally altered.	4,000	Lava-flow aquitard	Water movement controlled by poorly connected fractures; interstitial porosity and permeability negligible; coefficient of transmissibility estimated less than 500 gpd per ft; contains minor perched water in foothills between Frenchman Flat and Jackass Flats.
			Ash-fall tuff, tuffaceous sandstone, and tuff breccia, all interbedded; matrix commonly clayey or zeolitic.	1,700	Tuff aquitard	Coefficient of transmissibility ranges from 100 to 200 gpd per ft; interstitial porosity is as high as 40 percent, but interstitial permeability is negligible (6×10^{-3} to 6×10^{-6} gpd per sq ft); owing to poor hydraulic connection of fractures, interstitial permeability probably controls regional ground-water movement; perches minor quantities of water beneath foothills flanking valleys; fully saturated only beneath structurally deepest parts of Yucca Flat, Frenchman Flat, and Jackass Flats; Grouse Canyon and Tub Spring Members of Indian Trail Formation may locally be aquifers in northern Yucca Flat.
		Salyer Formation	Breccia flow, lithic breccia, and tuff breccia, interbedded with ash-fall tuff, sandstone, siltstone, claystone, matrix commonly clayey or calcareous.	2,000		
		(2)				
		Indian Trail Formation: Grouse Canyon Member	Ash-flow tuff, densely welded.	200		
		Indian Trail Formation: Tub Spring Member	Ash-flow tuff, nonwelded to welded.	300		
		Indian Trail Formation: Local informal units	Ash-fall tuff, nonwelded to semiwelded ash-flow tuff, tuffaceous sandstone, siltstone, and claystone; all massively altered to zeolite or clay minerals; locally, minor welded tuff near base; minor rhyolite and basalt.	2,000		
		(3)				
		Rhyolite flows and tuffaceous beds of Calico Hills	Rhyolite, nonwelded and welded ash flow, ash-fall tuff, tuff breccia, tuffaceous sandstone; hydrothermally altered at Calico Hills; matrix of tuff and sandstone commonly clayey or zeolitic.	>2,000		
	Miocene and Oligocene	Tuff of Crater Flat	Ash-flow tuff, nonwelded to partly welded, interbedded with ash-fall tuff; matrix commonly clayey or zeolitic.	300		
		Rocks of Pavits Spring	Tuffaceous sandstone and siltstone, claystone; fresh-water limestone and conglomerate; minor gypsum; matrix commonly clayey, zeolitic, or calcareous.	1,400		
	Oligocene	Horse Spring Formation	Fresh-water limestone, conglomerate, tuff.	1,000		

System	Series	Stratigraphic unit	Major lithology	Maximum thickness (feet)	Hydrogeologic unit	Water-bearing characteristics and extent of saturation[1]
Cretaceous to Permian		Granitic stocks	Granodiorite and quartz monzonite in stocks, dikes, and sills.		(A minor aquitard)	Complexly fractured but nearly impermeable.
Permian and Pennsylvanian		Tippipah Limestone	Limestone.	3,600	Upper carbonate aquifer	Complexly fractured aquifer; coefficient of transmissibility estimated in range from 1,000 to 100,000 gpd per ft; intercrystalline porosity and permeability negligible; saturated only beneath western one-third of Yucca Flat.
Mississippian and Devonian		Eleana Formation	Argillite, quartzite, conglomerate, conglomerite, limestone.	7,900	Upper clastic aquitard	Complexly fractured but nearly impermeable; coefficient of transmissibility estimated less than 500 gpd per ft; interstitial permeability negligible but owing to poor hydraulic connection of fractures probably controls ground-water movement; saturated only beneath western Yucca Flat and Jackass Flats.
Devonian	Upper	Devils Gate Limestone	Limestone, dolomite, minor quartzite.	>1,380	Lower carbonate aquifer	Complexly fractured aquifer which supplies major springs throughout eastern Nevada; coefficient of transmissibility ranges from 1,000 to 1,000,000 gpd per ft; intercrystalline porosity and permeability negligible; solution caverns are present locally but regional ground-water movement is controlled by fracture transmissibility; saturated beneath much of study area.
	?					
	Middle	Nevada Formation	Dolomite.	>1,525		
Devonian and Silurian		Undifferentiated	Dolomite.	1,415		
Ordovician	Upper	Ely Springs Dolomite	Dolomite.	305		
	Middle	Eureka Quartzite	Quartzite, minor limestone.	340		
	Middle	Pogonip Group: Antelope Valley Limestone	Limestone and silty limestone.	1,530		
	?					
	Lower	Pogonip Group: Ninemile Formation	Claystone and limestone, interbedded.	335		
	Lower	Pogonip Group: Goodwin Limestone	Limestone.	>900		
Cambrian	Upper	Nopah Formation Smoky Member	Dolomite, limestone.	1,070		
		Halfpint Member	Limestone, dolomite, silty limestone.	715		
		Dunderberg Shale Member	Shale, minor limestone.	225		
	Middle	Bonanza King Formation Banded Mountain Member	Limestone, dolomite, minor siltstone.	2,440		
		Papoose Lake Member	Limestone, dolomite, minor siltstone.	2,160		
		Carrara Formation	Siltstone, limestone, interbedded. Upper 1,050 feet predominantly limestone; lower 950 feet predominantly siltstone.	1,050		
				950	Lower clastic aquitard[3]	Complexly fractured but nearly impermeable; supplies no major springs; coefficient of transmissibility less than 1,000 gpd per ft; interstitial porosity and permeability is negligible, but probably controls regional ground-water movement owing to poor hydraulic connection of fractures; saturated beneath most of study area.
	Lower	Zabriskie Quartzite	Quartzite.	220		
		Wood Canyon Formation	Quartzite, siltstone, shale, minor dolomite.	2,285		
Precambrian		Stirling Quartzite	Quartzite, siltstone.	3,400		
		Johnnie Formation	Quartzite, sandstone, siltstone, minor limestone and dolomite.	3,200		

[1]Coefficient of transmissibility has the units gallons per day per foot (gpd per ft) width of aquifer; coefficient of permeability has the units gallons per day per square foot (gpd per sq ft) of aquifer.

[2]The three Miocene sequences occur in separate parts of the region. Age correlations between them are uncertain. They are placed vertically in table to save space.

[3]The Noonday(?) Dolomite, which underlies the Johnnie Formation, is considered part of the lower clastic aquitard.

bedded tuffs suggests that open fractures are rarely preserved in these rocks. Fractures observed in outcrops of the friable-vitric tuffs are filled with a clayey gouge-like deposit (Thordarson, 1965).

The tuffs have been divided into three types based upon their mineralogy and composition.

1) The zeolitic-bedded tuffs are found in Tunnel Beds 1 through 4 and portions of the Paintbrush Tuff. They were deposited by the fall of volcanic ash, which consisted predominantly of pumice and glass shards (Thordarson, 1965). This material was later massively altered, predominantly to the zeolitic minerals clinoptilolite, mordenite, and analcime. Minor amounts of clay minerals as well as some silica and hematite are also present (Thordarson, 1965). Non-zeolitic constituents generally make up 5 to 30 percent of the zeolitic bedded tuff. These are small crystals of quartz, feldspar, biotite, and dense lithic fragments.

2) The friable-bedded tuffs dominate in Tunnel Beds, Unit 5 and most of the Paintbrush Tuff. They were deposited as an ash-fall, but, in contrast to the zeolitic tuffs, the pumice and glass shards have undergone only minor alteration. The absence of zeolites and other cementing materials make these tuffs very friable. Only small quantities of quartz, quartzite, K-feldspar and plagioclase have been noted in Tunnel Beds, Unit 5 and the Paintbrush Tuff.

3) The welded and partially welded tuffs compose the Rainier Mesa member of the Timber Mountain Tuff, the Stockade Wash and Tiva Canyon members of the Paintbrush Tuff, the Grouse Canyon and Tub Spring members of the Belted Range Tuff, and portions of the Crater Flat Tuff. They were deposited as ash flows and welded together by their own heat and weight. Some of the units have friable, partially welded or nonwelded bases that grade indistinctly into welded tuffs. Sanidine, andesine, biotite, anorthoclase, quartz and plagioclase have been reported to occur locally in these tuffs (Hansen, et al., 1963; Emerick, 1966).

The chemical composition of the tuffs is more homogeneous than the physical composition. Silica concentrations vary only slightly between the different units of Rainier Mesa and cation concentrations, although more varied, remain within the same order of magnitude.

PRECIPITATION NETWORK

In order to provide baseline input data for many of the hydrogeologic investigations on the NTS, a precipitation network of 16 stations has been set up to collect precipitation samples for isotopic composition (Fig. 2). These are located around the NTS at different elevations. They are designed to suppress evaporation. Associated with each gauge is a suction lysimeter for sampling soil waters or gases.

The groundwater flow regimes on NTS have been studied for approximately 20 yrs. and are still not well understood. A large part of the problem is the low density of wells drilled for hydrologic purposes and still a smaller number from which good quality water chemistry samples may be obtained. At the present time the well density with pumps is one well per 200 sq. km.

The groundwater potentiometric surface indicates the flow on NTS should be generally south with several major deviations of flow. One major feature on the potentiometric surface is a trough in the Yucca and Frenchman Flat area. Waters recharged or flowing under the NTS are generally believed to discharge in the Amargosa Desert/Ash Meadows area, which are west and south of NTS.

126.0 STOP 6. SEDAN CRATER.

The crater was formed by a 100 kt. device as part of the Plowshare Program July 6, 1962. It is 340 m. across and 98 m. deep.

135.5 Drill yard on the left.

140.0 Driving through east Yucca Valley where collapsed craters can be seen on either side. DRI and USGS have been studying the infilration of water in the craters. They may represent important locations of groundwater recharge. Geophysics and soil moisture measurements have been used to track the movement of soil water as a function of crater size and age.

145.6 STOP 7. YUCCA LAKE.
Yucca Lake is a typical "recharging" playa. It is 14.25 km^2 in area. The depth to groundwater is greater than 450 m. It receives approximately 200 mm/yr precipitation with a potential evaporation of 1,700 mm/yr. Several times a year the playa is covered with a shallow lake receiving runoff from adjacent areas.

175.7 Mercury, Nevada.

202.0 Lathrop Wells, Nevada -- Note large sand dunes to the left (south) of the highway. To the right is Yucca Mountain, the site of a proposed High Level Nuclear Waste Repository.

231.0 Beatty, Nevada -- Spend the night near U.S. Ecology - a low level nuclear waste disposal site.

DAY 2
SOUTHERN AMARGOSA DESERT

The following field trip to the Southern Amargosa Desert is a modification of ones run during the March 1974 Geological Society of America Cordilleran Section Meeting, Las Vegas, Nevada (Naff, et. al., 1974) and the September 1979 Sixth Conference on Karst Hydrogeology and Speleology. Mileages are approximate.

231.0 Beatty, Nevada
U.S. Ecology
Yucca Mountain

260.0 Lathrop Wells, Nevada -- Turn right on State Route 373.

275.3 Turn left onto paved road - turns to gravel.

276.5 Clay Camp. In the abandoned clay pits (the clay mined here was used in filters) structures and stratigraphy of the Tertiary and later valley fill may be seen. Near this point Ash Spring discharges water of very different quality from the water in the valley of the Amargosa River to the west or from that in Ash Meadows to the east. The flow system here exhibits a relatively high "ridge" with discharge points several feet higher than is discharged either to the east or west. This ridge is obviously closely related to the complexly faulted and folded Tertiary valley fill in this area. The groundwater ridge is obviously accentuated by low water levels resulting from evapotranspiration of ground water to the east in Carson Slough.

281.4 STOP 8. CRYSTAL POOL.
Spring (Turn right through gate to spring).

A typical large spring representing discharge from the Ash Meadows ground-water system. Temperature of the water is 31°C with an electrical conductivity of 650 μmhos and a discharge of 15,700 m^3/day. Total spring discharge from the aquifer at Ash Meadows is approximately 58,000 m^3/-day. The average carbon-14 content of Crystal Pool is 11.1% modern while the average for the other springs in the area is 2.3% modern (Winograd and Pearson, 1976).

282.3 Turn right on County Road.

284.8 Turn left.

286.2 Turn left.

286.3 STOP 9. DEVIL'S HOLE.

This location demonstrates the role of reservoir mechanics in relation to the problem of preserving an endangered species, the Desert Pupfish. Pumping of the alluvial aquifer for agricultural purposes lowered the water level in Devil's Hole, a karst fenster. Water temperature is 33.5°C.

286.4 Turn right.

287.5 Turn left.

288.0 Turn left.

289.7 STOP 10. POINT OF ROCKS SPRING -- Lunch.

Another spring discharging from the Ash Meadows groundwater system. The discharge is approximately 8,400 m^3/day with a temperature of 33°C and an electrical conductivity of 660 µmhos.

306.2 Continue to the east on road. *Intersection of Bellvista Road and* Leslie Street. Turn right.

307.2 Turn left on to Mesquite.

309.6 Turn right on to Route 160.

312.4 Pahrump Valley.

324.2 Road to the left goes to Trout Canyon. Several caves are in the canyon including Deer Spring Cave.

332.0 Road to the right goes to Tacopa Hot Springs.

348.1 Mountain Springs Summit.

348.8 Road to left goes to Potosi Mine and Pinnacle Cave in the Potosi Mountains.

349.5 Cross the Keystone Thrust fault in which Jurassic Aztec Sandstone has been thrust over the Paleozoic carbonates.

352.7 Gypsum Mine on the right.

361.1 STOP 11. REDROCK OVERLOOK. *The general stratigraphy and structure of the Las Vegas area may be* observed from this location.

Bedrock here consists of Permian Kaibab Limestone very close to the Permian-Triassic boundary. Looking westward the valley is cut into the Moenkopi Shale. The Shinarump Conglomerate forms the small dark hogback on the west side of the valley. It is overlain successively by the Chinle (purplish and red beds), the Kayenta, and the cliff-forming Aztec Sandstone. The Aztec, in turn, is overlain by Paleozoic limestones which were thrust over the Aztec in Laramide time (Keystone and Red Rock thrust faults). Breccia believed to be the sole of the thrust is draped over the Aztec and underlying rocks in a few places. The Keystone and related thrusts did not displace the crust as much on the southwest side of Las Vegas Valley as the Muddy Mountain and related faults did on the northeast side. This resulted in a shear zone now occupied by Las Vegas Valley. This shear zone extends under the Tertiary volcanic rocks of the River Mountains and McCullough Range to the south. It extends northward beyond Indian Springs, and is believed to be associated with the Walker Lane, possibly intersecting the latter.

362.1 STOP 12. REDROCK MUSEUM.

375.4 STOP 13. Las Vegas Valley Water District Well Field.

This is the West Charleston well field, an area (about 1/2 section) which has been chief source of the supply of groundwater for Las Vegas Valley. The site of Big Spring was at the north end of the well field about 0.5 km. east of here. It supplied the city for many years, until pumping from wells reduced the head and the spring stopped flowing (about 1947).

Note the scarp at this location, one of the several scarps believed to be the result of differential compaction of the valley-fill materials. Another (possibly two?) such scarp occurs west of here, and the largest scarp occurs a few kilometers to the east in the eastern part of Las Vegas and the western part of North Las Vegas. All of these scarps are aligned north-south and veer to the northeast of Las Vegas. Relationship to tectonic features in the bedrock has been searched for, but none has ever been discovered. Since the scarps occur where the lithology changes from predominantly gravel and sand on the west to predominantly silt and clay on the east they are interpreted as differential compaction features. Evidence of subsidence as a result of withdrawal of groundwater has been observed along most of the scarps. Cracking at the surface, vertical extrusion of well casings, displaced water mains, and displaced and distorted structures, all attest to such subsidence. Correlation between fluctuations in withdrawal of water and subsidence has been documented.

The Las Vegas Valley groundwater system roughly occupies the watershed area of Las Vegas Valley but may be connected hydraulically with systems contiguous to it, especially to the north (Ash Meadows system), and to the northeast (White River Valley system). Little is known of the deeper part of the system (below about 600 m.) since only a few oil, brine, and geothermal test wells have been drilled. The deepest reported test hole is approximately 2600 m.

379.7 Return to the Las Vegas Airport. Trip ends.

ACKNOWLEDGEMENTS

The leaders would like to thank the following people who contributed parts of this guidebook: Clinton M. Case for a discussion on the Radioactive Waste Management Site; Paul R. Fenske for the Historical Background and part of the RNM program; Richard H. French for contributing the Flood Hazard evaluation; Martin D. Mifflin for writing the section on the Las Vegas Valley Badlands; Stephen W. Wheatcraft for the discussions of the RNM program and the many graduate students including Mark S. Henne, Donald S. Hansen, Carol J. Boughton and Sarah L. Raker who have contributed M.S. Theses on the NTS through the years.

REFERENCES

Daniels, W. R., Ed., 1981, Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1979 - September 30, 1980: Los Alamos National Laboratory, Dept. LA-9192-PR.

Emerick, W. L., 1966, Physical Properties of Volcanic Rocks, Rainier Mesa and Vicinity, Nevada Test Site: USGS Technical Letter: Area 12-18.

Fairer, G. M., Townsend, D. R., Carroll, R. D., Cunningham, M. J., Muller, D. C., Healey D. L., and Ellis, W. L., 1979, U.S. Geological Survey Investigation in Connection with the Mighty Epic Event, U12n.10 Tunnel, Nevada Test Site: USGS 474-228.

Fenske, P. R., 1978, Interaquifer Leakage Through Uncored Boreholes Penetrations, Yucca Valley, Nevada Test Site: Desert Research Institute, NV, Report Series 45013, University of Nevada, Reno.

Hayes, C. V., 1967, Quaternary geology of the Tule Springs Area, Clark County, Nev., Nev. State Museum Anthro. Papers No. 13, 104 p.

Jacobson, Roger L., and Hess, John W., 1984, Time Series Analysis of Geochemical and Isotope Data in Semi-arid Regions, Geochemical Symposium in Banff, Canada, June 22-26, 1984.

Kautsky, M., 1984, Sorption of Cesium and Strontium by Arid Region Desert Soil. Water Resources Ctr., Desert Research Institute, University of Nevada System, Reno.

Kearl, P. M., 1982, Water Transport in Desert Alluvial Soil. Water Resources Ctr., University of Nevada System, Reno, Pub. No. 45024, 130 p.

Mifflin, M. D., 1968, Delination of groundwater flow systems in Nevada, Desert Research Institute, CWRR, Tech. Rpt., Series H-W, Publ. 4, 111 p.

______, and Wheat, M. M., 1979, Pluvial Lakes and Estimated Pluvial Climates of Nevada, Nevada Bureau of Mines and Geology Bulletin 94, University of Nev., Reno.

Moore, J. E., and Garber, M. S., 1962, Ground-water test well B, Nevada Test Site, Nye County, Nevada: U.S. Geol. Survey TEI-836, Open File Report, 73 p.

______, and Garber, M. S., 1962, Ground-water test well B, Nevada Test Site, Nye County, Nevada: U.S. Geol. Survey TEI-808, Open File Rept., 39 p.

Naff, R. L., Maxey, G. B., and Kaufmann, R. F., 1974, Interbasin Ground-Water

Flow in Southern Nevada, Nevada Bureau of Mines and Geology Rpt. 20, 28 p.

Panian, T., 1984, Master's Thesis in progress, University of Nevada, Reno.

Poole, F. G., Elston, D. P., and Carr, W. J., 1965. Geologic map of the Cane Springs Quadrangle, Nye County, NV, U.S. Geol. Survey, Geological Quad. Map EQ455.

Quade, J., 1982, Quaternary Geology of the Corn Creek Springs Area, Clark County, Nevada, Tucson, University of Arizona MS Thesis, 130 p.

Thordarson, W., 1965, Perched Ground Water in Zeolitized-Bedded Tuff, Rainier Mesa and Vicinity, Nevada Test Site, Nevada, USGS TEI-862, 90 p.

Van Genuchten, R., 1978, Calculating the Unsaturated Hydraulic Conductivity with a New Closed-Form Analytical Model, Dept. of Civil Engineering, Princeton Univ., New Jersey.

Winograd, I. J., and Thordarson, W., 1975. Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site, U.S. Geol. Survey Prof. Paper 712C, 126 p.

______, and Pearson, F. J., 1976, Major Carbon-14 Anomaly in a Regional Carbonate Aquifer: Possible Evidence for Megascale Channeling, South Central Great Basin, Water Resources Research 12:6, p. 1125-1143.